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التاريـــخ: 2/8/2012

نموذج رقم (18)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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تخصص: الهندسة المعمارية **الكليـــــــة:** كلية الهندسة و التكنولوجيا

عنوان الرسالة:

The Planning and Design of Vertical Farms: Prospects For Urban Farming In Palestine

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

توقيع الطالب:.................. التاريخ: 2/8/2012

THE PLANNING AND DESIGN OF VERTICAL FARMS :PROSPECTS FOR URBAN FARMING IN PALESTINE

By

Ghadeer Abdallah Ahmad Derbas

Supervisor

Dr. Prof. Nabil Abu Dayyeh

This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Architecture

Faculty of Graduate Studies
The University of Jordan

August, 2012

II

COMMITTEE DECISION

This Thesis /Dissertation (The Planning and Design of Vertical Farms: Prospects For Urban Farming In Palestine) was successfully defended and approved on 25/ 7/ 2012

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DEDICATION

To my Father and my Mother

To My Family

To my Friends

AKNOWLEDGEMENT

I would like to thank my parents, my sisters and brothers, all my family, and my friends for their ongoing support and encouragement throughout my life. I also would like to thank my supervisor Dr. Nabil Abu Dayyeh for support, and guidance.

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LIST OF ABBREVIATIONS OR SYMBOLS

Abbreviation	Word
ARIJ	The Applied Research Institute Jerusalem
BC	Before Christ
CFSC	Community Food Security Coalition
CO2	Carbon Dioxide
ETFE	Ethylene Tetra Fluoro Ethylene
FAO	Food and Agriculture Organization
IFAD	International Fund for Agricultural Development
KW	kilo Watt
LED	Light- Emitting Diodes
LEED	Leadership in Energy and Environmental Design
NFT	Nutrient Film Technique
O2	Oxygen
OLED	Organic Light Emitting Diodes
PCBS	Palestinian Central Bureau of Statistics
PH	Hydrogen ion concentration
PV	Photovoltaic Panel
PVC	Polyviny1 Chloride Plastic
RUAF	Resource center on Urban Agriculture and Food security
SITE	Sculpture In The Environment
TANU	Tamil Nadu Agricultural University
UAA	Urban Agricultural Architecture

UN	**United Nations**
UNDP	**United Nations Development Program**
UNPF	**United Nations Population Fund**

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THE PLANNING AND DESIGN OF VERTICAL FARMS: PROSPECTS FOR URBAN FARMING IN PALESTINE

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ABSTRACT

The focus of this research is to assess the potential for introducing vertical farming in Palestine country, and evaluate its viability and sustainability.

The key questions this thesis has aimed to address are whether Vertical Farming is a viable solution to our food scarcity, considering our acute water shortage, and lack of agricultural land? Having established that, the second step was to formulate the general guidelines for the design of a prototype for a Vertical Farm, and the criteria that would govern the choice of an appropriate location?

In exploring this theme, this study proceeds to plan and conceptualize of a model, Vertical Farm, which can be suitable for erecting within urban context.

Conclusions are reached that the proposed Vertical Farm would consist of (10) stories, with a total area of (12,000) m^2, requiring at least (3) dunums of land, with an estimated cost of JD (15) million, such a project would achieve several goals: total crop production of proposed Vertical Farm would equal (4-45) times crop production using

traditional farming methods. In addition, the same quantity of crops produced by the proposed vertical farm will need (150) dunums of arable land using traditional farming methods.

In the end, some practical recommendations are proposed to make the concept of vertical farming come to reality through the corporation of local governments, researches, architects, economists and agricultural engineers.

Introduction

"For the more than one billion people who, through no fault of their own, go to sleep hungry each night, and for the three billion more who will most likely arrive on this planet over the next forty years to join them in their suffering…if nothing changes"

Dickson Despommier

Today, over (800) million hectares are committed to soil based agriculture, making up for 38% of the total land area of the earth. Over the next (50) years, human population is expected to rise by at least (8.6) billion, requiring an additional (109) million hectares to feed them using current technologies. That quantity of additional arable land is simply not available (Despommier, 2010).

Water scarcity is another global threat; more than two-thirds of the world's fresh water is used for agriculture. Depletion of water resources is exacerbated by expanding cities, global warming and more droughts (Cho, 2011).

Novel ways for obtaining an abundant and varied food supply without encroachment into remaining echo-system must be seriously investigated. One solution is Vertical Farming; a new approach to urban food production can be erected in the middle of urban centers (Despommier, 2004).

Dr. Dickson Despommier, a Professor of Environmental Health Sciences at Columbia University, and (105) graduate students came up with concept of the Vertical Farm- a multi-story building growing layers of crops on each floor using hydroponic, aeroponic and aquaponic crops. Hydroponics use 70% less water than conventional

agriculture, while aeroponics use even less water, and nutrients not taken up by the plants are recycled.

At present, lettuce, leafy greens, herbs, strawberries and cucumbers are the most commonly grown crops in vertical farm, but in theory, corn and wheat could be grown.

As a balanced mini-echo system, the vertical farm has many advantages. A vertically farmed acre can produce the equivalent of (4-6) soil- based acres, depending on the crop. Plants can be grown year-round, unaffected by weather conditions such as droughts, floods or pests. Vertically farmed food is safe from contamination, and is grown organically without the use of fertilizer, pesticides or herbicides (Cho, 2011).

Fossil fuel use is minimal because there's no need for farm equipment, transportation of produce into cities, storage or distribution. Vertical farm can exploit unused urban centers, providing surrounding neighborhoods with fresh produce, and also creating new job opportunities.

Two year ago (from the year of thesis writing), no vertical farms existed. Now, the modestly sized vertical farms are springing up around the world such as, Nuvege in Japan, and Plant Lab in Den Bosch. And there is interest around the world from Newark, China, Singapore, Doha, Vancouver, Milan, Amman, Riyadh, and Las Vegas. As more vertical farms are created the engineering and technology will continue to evolve (Cho, 2011).

Considering its particular geospatial and political circumstances, Palestine could be the next one to have a vertical farm building. During the last few years, Palestine was exposed to food scarcity in most of its major cities. Today, it is predicted that the total population of West bank and Gaza will be up to (6) million people by 2025.

Furthermore, in 2015, (240,000) returnees are expected to be added to the current population (Palestinian Central Bureau of Statistics -PCBS, 2008).

Meanwhile, local agricultural production is limited and unstable due to changing climatic conditions, and lack of access to land because of Israeli restrictions. So, the concept of vertical farm within the urban centers of cities may act to mitigate such food shortages.

Therefore, this thesis research focuses on studying the feasibility of constructing the first Vertical Farm in Palestine, conceptualizing a proposed model design of a Vertical Farm building, and defining the main criteria for potential site locations.

CHAPTER ONE

RESEARCH SUMMARY

Imagine a building located within a large metropolitan center that has a negative carbon footprint, produces food crops in commercial quantities, and stands out as one of the most beautiful, transparent multi-story iconic structures in the entire city. That is what is envisioned for the vertical farm of the near future.

Bringing such a building into reality will require no new technologies, since we already know how to construct ones that favor the growth of a wide variety of plants, including most crops that the world at large consumes (grains, vegetables, herbs, fruits). These structures are high-tech, energy-efficient greenhouses, that practice closed loop controlled environment agriculture, and examples of them can be found throughout the developed world (Despommier, 2010).

1.1. Introduction:

By 2050, the world population will increase to (9) billion people; nearly 80% of them will reside in urban centers. Rapid climate change issues will play a major role in agriculture, it is estimated for every one degree of increase in atmospheric temperature, 10% of the land where we now grow food crops will be lost (Despommier, 2010), which means that food production will be a considerable issue, and we have to think how we will feed all these people.

Vertical farming is the optimum and legitimate solution, instead of implanting horizontally; the cultivation of agricultural products will be vertically in multi-storey building structures, inserted within urban centers close to where people live (Ankri, 2010). It is an intensive farming strategy which mainly employs advanced techniques such as hydroponic and aeroponic to produce crops like fruits and vegetables (Crop Farming Review, 2010).

In 1915, the phrase "Vertical Farming" was coined by Gilbert Bailey. Architects and scientists have repeatedly looked into the idea since then. In 1999, Dickson Despommier, a Professor of Environmental Health Sciences at Colombia University seized upon the idea together with his students (Wikipedia, December, 2010).

Vertical farming has many advantages and plenty of benefits. Environmentally, it can handle with climate changes, and reduce CO_2 emissions by eliminating long distance transportation of goods (M. Collin and William Collin, 2009); sustainable and organic production will avoid the use of pesticides or fertilizers, and water and waste management. Economically, it will reduce the cost of food products, as (1) indoor acre is equivalent to (4-6) outdoor acres or more, depending on the crop (Despommier, 2010). And socially, it will create new job opportunities and education for the community (M. Collin and William Collin, 2009).

1.2. Research Problem and Hypothesis:

1.2.1. Research Problem:

The concept of vertical farming is beginning to catch on around the world. Developers and local governments in Korea, China, USA, and United Arab Emirates, are all interested in adapting this idea of Vertical Farming (Mahajan, et al., 2010).

So, the research problem aims to explore the viability of Vertical Farming in Palestine, in terms of energy, water, transport, waste and organically produced food. This will entail the study of different technologies and techniques involved in the design of the proposed vertical farm building, which will include the study of both hydroponic systems, and "Green Building" strategies (i.e. natural day lighting and ventilation system, heating and cooling system, water and waste recycling system, and how to capture renewable energy such as solar energy, wind energy, and biogas). Then research

will define the main guidelines of the proposed vertical farm design, and main criteria for potential vertical farm locations.

1.2.2. Research Hypothesis:

The current thesis work will address the following three research questions:

- **First**, is vertical farming a viable solution to Palestine food scarcity, water shortage, and loss of agricultural land problems?
- **Second,** what are the general guidelines of vertical farm building design?
- **Third**, what criteria govern the choice of an appropriate location? And how does it relate to its surroundings?

1.3. Significance of the research:

At the rate that agricultural land used for food production is diminishing and the population increasing, it is expected that food scarcity will be the next biggest problem we have to contend with. Most of our planet's natural resources have eroded due to intensive farming, while other land areas have been devoted to industrial and suburban uses (Rassia and M. Pardalos, 2011).

On the local perspective, Palestine faces a protracted crisis characterized by access restriction to natural resources, water and land (Minister of Agriculture Palestinian Authority, 2009). Low economic access to food production, and low domestic food production and high dependency on imported food 80–90% for most staple commodities) are root causes of food scarcity in Palestine, (Food and Agriculture Organization (FAO) of the United Nation, 2009). At the same time, arable land is fast decreasing due to population growth, unsustainable conventional agricultural methods,

and global warming. Moreover, during this period of political instability, agricultural land has often been converted to urban built-up areas (AL Hudhud, 2007).

In the light of water scarcity which jumped from (1,322) m^3 in 2005 into (30,697) m^3 in year 2025, and the decrease of the per capita available land from (150) m^2 in year 1989 to (78) m^2 in year 2000, food production issues will be further complicated (AL Hudhud, 2007).

In order to address these challenges, this research aims to study the viability of **"Vertical Farming"** which allows for greater productivity much closer to the source of consumption, and increases the local food production without need of more arable land.

Furthermore, Vertical Farming technology includes hydroponics which uses 70% lesser water than traditional farming methods. So, this will reduce the incidence of armed conflict between Palestinians and Israelis over natural resources such as water and land for agriculture.

1.4. Research Objectives:

The main objectives of the research are:

- To study the viability of vertical farming in our region, particularly in Palestine.
- To plan and conceptualize a prototype version of a Vertical Farm that can be erected in an urban or suburban setting.

In order to conceptualize a prototype version of vertical farming, the research will study and measure the best shape of building, its footprint and height, the selection of proposed Vertical Farm crops, their arrangement in each floor, methods of cultivation (drip irrigation, hydroponic, or aeroponic), day-lighting system, water irrigation and energy demand, and materials of construction.

In order to locate the building within a proposed urban center, the research will study the optimum locations close to water resources, food consumption, and markets, and study the relationship with context.

1.5. Methodology of Research:

To achieve our goals, the following methodology was followed:

The basic data is collected from different and wide sources of information including:

1. Newspapers, reports, books, magazines, articles and many others.
2. Interviews and exchange experiences with local professionals of hydroponic agricultural system in both Jordan University of Science and Technology (JUST), and National Center for Agricultural Research and Extension (NCARE).
3. Field trips to different greenhouse locations that experiment with hydroponic systems to cultivate different crops such as strawberries and tomatoes in JUST Campus in Irbid in Jordan.

This research makes use of the following data and analysis:

1- Study Area Background:

- Location.
- Weather/climate in Palestine.
- Food security in west bank.
- Agriculture production in Palestine.
- Current and future water availability.
- Potential of renewable energy.

2- Technologies and Techniques of Agriculture:

- Equipment and techniques of hydroponic and aeroponic agriculture.
- Water treatment\recycling.
- Drip irrigation system.
- Waste management.

3- Building Energy Requirements:

- Energy demand for building operation.
- Renewable energy as alternative source.

4- Building Design Requirement:

- Plant design requirement.
- Hydroponic\aeroponic system requirement.
- Green building design requirement.

5- Crop Requirement:

- Criteria of crops selection.
- Environmental requirement of selected crops.
- Harvesting and post harvesting techniques of selected crops.
- Packaging tools and storage conditions.

1.6. Limitation of the Research:

This research was circumscribed by the following limitations:

- Ideally, Vertical Farming would be a team work project for a team composed of architects, urban planners, agricultural and civil engineers, economists and others in partnership with local governments.
- Lack of expertise and knowledge of practical hydroponic system at local levels except for some experiments done on a very limited number of crops such as tomatoes and strawberries.

- Lack of practical application of green building design technologies for capturing renewable energy sources such as Photovoltaic (PV) solar panels, wind turbines, except for some small-scale projects.

CHAPTER TWO

LITRATURE REVIEW

This chapter will be an introduction of the major global issues behind the concept of vertical farming, from increase of population, climate change, rapid urbanization, water scarcity, pollution and high food prices. Then, it will be a brief background of urban agriculture and its forms.

2.1. Part One: Major Global Issues in the 21st century

Farming catalyzed our transformation from primitive hunter-gatherers to sophisticated urban dwellers in just (10,000) years. Today, over (800) million hectares is committed to soil-based agriculture, or about 38% of the total land area of the earth. (Food and Agriculture Organization (FAO), World Health Organization, 2004).

Despite the obvious advantage of not having to hunt for our next meal, farming has led to new health hazards by increasing transmission rates of numerous infectious disease agents such as influenza, rabies…etc. Otherwise, the world society faces many serious crises, as will be illustrated in the following pages, such as population increases, deforestation, climate change, pollution, depleting resources, dwindling ecology, decreasing food supplies, and other related problems.

2.1.1. Increase of population and Hungry crisis:

Thomas Malthus is an English political and demographer who expressed views on population growth and noted the potential for populations to increase rapidly than the food supply available to them. Is mathematician Malthus's 200-year old prediction that the human growth will one day outpace agriculture, finally coming to pass? Kuang Asked (Kuang, 2008).

Over the next (50) years, it is predicted that the human population will rise to at least (9) billions, requiring an additional (109) million hectares to feed them using current technologies, or roughly the size of Brazil (as illustrated in *Figure 2.2*). That quantity of additional arable land is simply not available (Despommier, 2010). How this will be accomplished is more than problematic, since we now use some 80% of the land that can be farmed for food production (Monfreda et al. 2008).

Despite technological advances that have modernized the conditions of production and distribution of food, hunger and malnutrition still threaten the health and well-being of millions of people around the world. In fact, 80% of the world's hungry are directly involved in food production. It is estimated that (1 in 7) people go to bed hungry every night which is almost one billion people worldwide, and about (35,000) people around the world die each day from hunger (Koc et al., 1999, p.p.1-11).

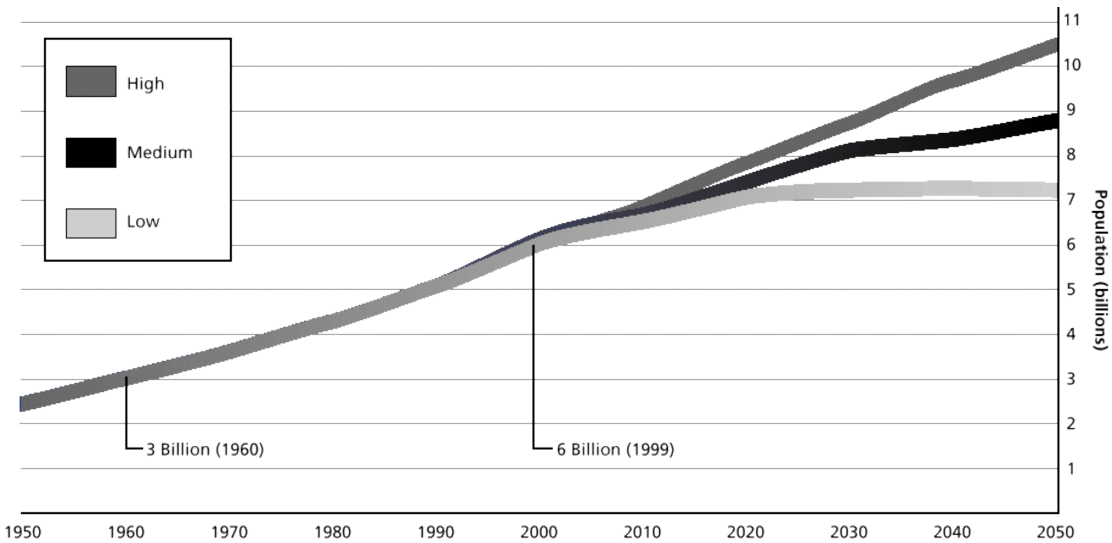


Figure 2.1 World Population Growth, actual and projected, 1950-2050
Source: United Nation (UN), 1998, world population prospects, http://englishonline.tki.org.nz, retrieved May 23, 2012.

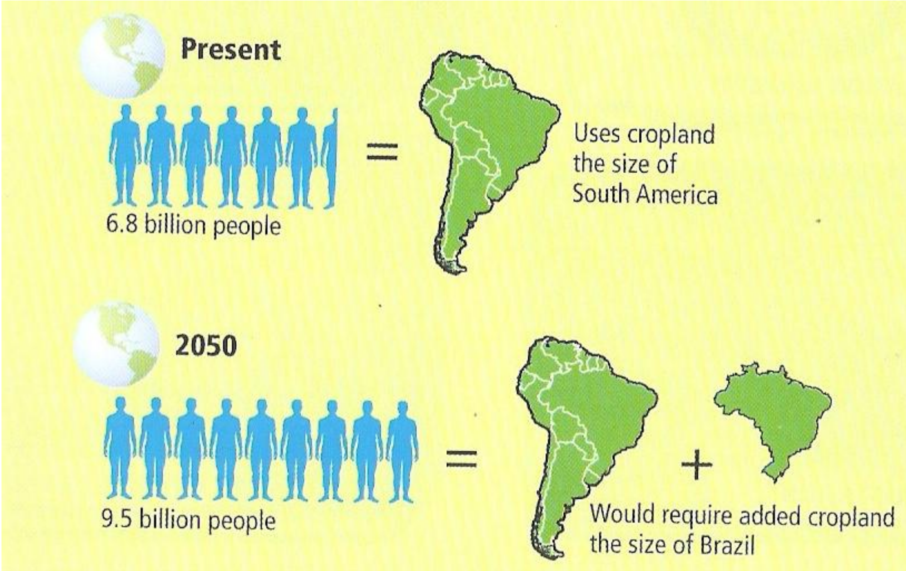


Figure 2.2 Population Growth and Agricultural land use,
source: (Despommier, 2012, p.p.77)

2.1.2. Climate change:

Over the next (50) years, rapid climate change issues will play a major role in agriculture. It is estimated for every (1^{o}C) of increase in atmospheric temperature, 10% of the land where we grow food crops will be lost, climate changes will also accelerate even more due to forestation, as forests are being sacrificed for farmland, and then the carbon cycle will be out of balance and get worse if nothing is done on a global scale. In addition, soil erosion due to floods and droughts completes the picture of climate change issues which have reduced where we grow our food (Despommier, 2010).

2.1.3. Rapid urbanization:

The United Nations estimates that by 2050, 80% of the world's population will live in cities, because of natural increases in urban populations and rural-to urban migration (Edward, 2011). Urbanization poses a considerable threat to all dimensions of food security, because the majorities of urban dwellers are net food buyers and spend a large part of their disposable income on food (Matuschke, 2009).

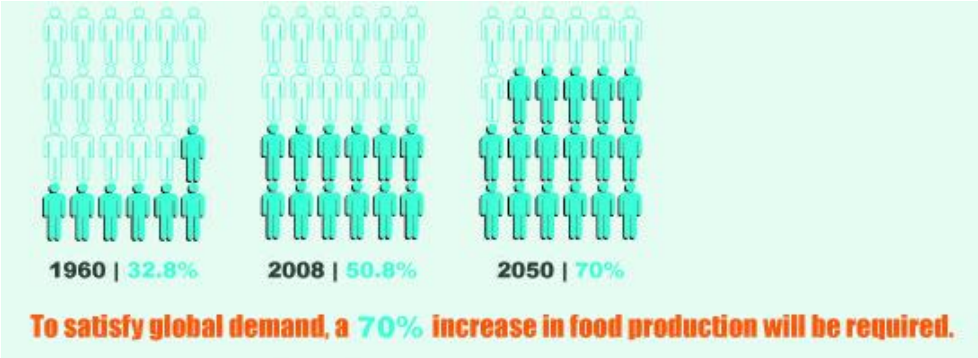


Figure 2.3 Percent of Global Population living in urban areas in 1960, 2008, 2050.
Source: UN, world urbanization prospects.

2.1.4. Pollution and increase of CO_2 emissions :

Also the ecological footprint of cities will increase enormously. Cities now are responsible for 70% of the world's CO_2 emissions, a large part of which comes from transportation and the supply of food (Mees, 2012). It is estimated that a single calorie of food requires (10 to 15) times fossil fuel energy for its production and distribution (Singhal, 2009).

2.1.5. Water scarcity:

One study has calculated that if present trends continue, (1.8) billion people will be living in absolute water scarcity by 2025, while a full two thirds of the human population will face water stress (Gordon, 2012).

According to the UN water database, there are (7) billion people requiring (2-4) liters of drinking water daily\capita, and (2-5) thousand liters daily\capita to produce their food requirements.

2.1.6. Rising of food prices:

According to FAO, growing world population, urbanization and diversion of agricultural land for commercial purposes, increasing scarcity of fresh water for

irrigation, low crop yield, and neglect of investment in agricultural technology, all these factors are responsible for the rising trends of global food prices (Rahman, 2011).

Figure 2.4 FAO Food Price Index (1990-2012)
Source: http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/, retrieved May 23, 2012.

The above *Figure (2.4)* illustrates the food prices index of the food and agricultural organization from 1990 to 2012. In 2011, the benchmark index for food prices exceeded the steepest price level on record in 2008.

From the above problems, it really should find a solution, and Vertical Farming has the potential to address all of these issues, as it can dramatically reduce de-forestation as there is far less land needed for Vertical Farming than the traditional farming methods, it can help to reduce urban sprawl with less processing factories, transport axis and transport infrastructure, and it can reduce pollution by dramatically reducing the transport loads, chemicals and other pesticides used in more recent farming.

2.2. Part Two: Brief History of Urban Agriculture, and its forms

Urban agriculture has much to offer cities by allowing food to be produced locally, reducing the carbon footprint of transportation, and creating green spaces by urban farms which can enhance the city's aesthetic appeal. The city- dwellers, too, can receive fresh fruits and vegetables (Singhal, 2009). Today, urban agriculture is also part of the call for a sustainable and healthy lifestyle (Mees, 2012).

2.2.1. Definition of Urban Agriculture:

At first glance, the term "Urban Agriculture" may appear to be an oxymoron. Agriculture is commonly considered as a rural activity, urban agriculture defined as:

"an industry that produces, processes, and markets food, fuel, and other outputs, largely in response to the daily demand of consumers within a town, city, or metropolis, on many types of privately and publicly held land and water bodies found throughout intra-urban and peri-urban areas" (Smit et al., 2001, p. 1).

2.2.2. Brief History of Urban Agriculture:

Urban Agriculture has been found as long as there have been cities, the lack of a sophisticated transportation systems or refrigeration meant that people were forced to live and farm within the city (Skaife, 2012). Urban agriculture has played a major role in cities for a very long time, such as, in ancient Egypt, community wastes were used to feed urban farming (Wikipedia, February, 2012).

After the industrial revolution, the close relationship between people and food was dramatically changed. During the industrial revolution, more and more people were moving into cities to work in factories, technology needed to build a great network of railways became widely available, so people and goods could be easily transported great

distances, leaving millions of people separated from food production which was pushed outside city (Skaife, 2012).

The separation of urban dwellers from agriculture largely continued until the first and second World Wars. The threat of starvation from wartime blockades pushed citizens to increase domestic food production. A National **Victory Garden** Program was instated during the Second World War as a way to establish functioning agriculture within cities. The popular program produced over (9) million pounds of fruit and vegetables per year, which was 44% of U.S. grown produce at the time (Skaife, 2012).

Figure 2.5 Ancient Egypt urban farming

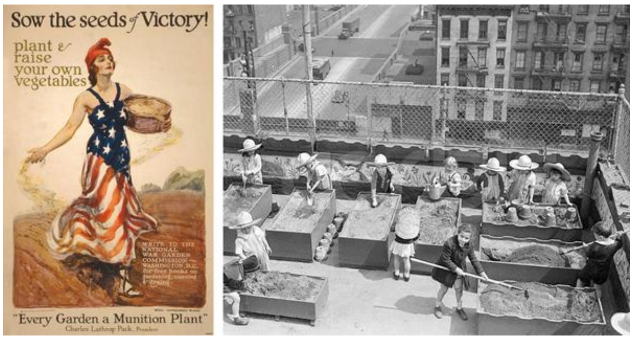


Figure 2.6 Victory gardens in USA during the second World War

Source: http://hoerrschaudt.com, retrieved February 25, 2012

The renaissance of Urban Agriculture throughout the world has been greatly influenced by the permaculture[1] movement, which was developed by Australians Bill Mollison and David Holmgren during 1970s. Urban Agriculture is a movement responding to new global demands of peak oil, climate change and flaws in our current food model. And there is a need for new ways of conceptualizing Urban Agriculture and ways to integrate it into our cities through policy change and smart design solutions that meet today's needs (Skaife, 2012).

[1] Permaculture is a theory of ecological design which seeks to develop sustainable human settlement agricultural systems. It was developed by Australians Bill Mollison and David Holmgren during 1970s. The word "permaculture" originally referred to "permanent agriculture", but was expanded to also stand for "permanent culture" as it was seen that social aspects were integral to a truly sustainable system (http://en.wikipedia.org/wiki/Urban_agriculture, retrieved February 25, 2012).

2.2.3. Integration between Urban Agriculture and Architecture:

Urban planners and architects should change their approach towards food security and Urban Agriculture. To achieve that a new practice of integrating organic, hydroponic, aeroponic, and aquaponic farming technologies into building of all types is called **Urban Agricultural Architecture (UAA)**. The building can be small as greenhouse which is attached to single family home, or a large scale project such as vertical farm building (Wikipedia, April, 2012).

2.2.4. Urban Agricultural Forms:

Food production in the cities can take many forms, including home gardens, community gardens, market gardens, school gardens, rooftop gardens, windowsill gardens, aquaculture, and urban farms. The choice of production method will vary due to the circumstances of each community (Grewal S.S. and Grewal P.S., 2011).

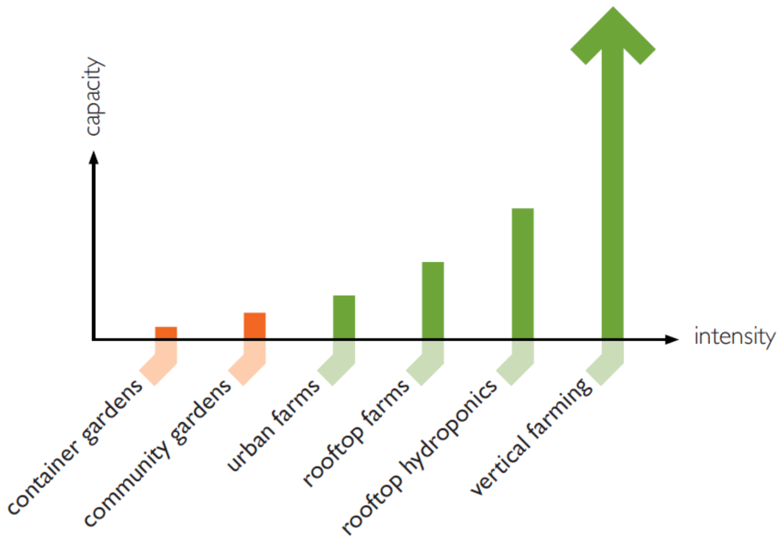


Figure 2.7 Urban Agricultural Forms Development
Source: (Despommier, 2010)

1. Urban Farms:

Urban farms are the primary form of urban agriculture. Urban farm can vary widely in size and scale, so it is divided into three categories: recreational farms (consist of less

than 100 acres), adaptive farms (range in size from 100 to 200 acres), and traditional farms (larger than 200 acres).

2. Community Gardens:

Community gardens are another example of urban agriculture. It can be defined as large lots of land that have been divided into smaller plots for each household's use. These lots can be owned by a municipality, an institution, a community group, a land trust, or private ownership (Community Food Security Coalition's (CFSC), October, 2003).

3. Rooftop Gardens:

"It is the practice of cultivating food on the rooftop of buildings. Rooftop farming is usually done using hydroponics, aeroponics, or container gardens" (Wikipedia, April, 2012).

There are essentially three options for rooftop gardens. The first is container gardening, a less formal, cheaper form of roof gardening. In the second type, the rooftop garden becomes the planting medium and offers a temporary habitat to fauna such as birds and butterflies during their long migrations. The third rooftop garden is rooftop hydroponics, in which plants are grown in a soilless medium and fed a special nutrient solution (Nowak, 2004).

4. Vertical Farming: It is a new sustainable approach of urban agriculture which will be discussed in the next section.

(A) Urban Farms
Source: http://farm4.static.flickr.com

(B) Community Garden
Source: http://www.anthonyzierhut.com

(C) Rooftop Garden
Source: http://www.bridgman.co.uk

(D) Vertical Farms
Source: http://www.archidose.org

Figure 2.8 Urban Agricultural Forms integrated to building

CHAPTER THREE

VERTICAL FARMING

In the few past years, the human population is growing exponentially, and many echo-friendly solutions are being examined to meet people food need. Whereas conventional farms are horizontally oriented, vertical farming is a new approach that grows food on a vertical axis which reduces the vast amounts of land from agriculturally associated damage (Despommier, 2004).

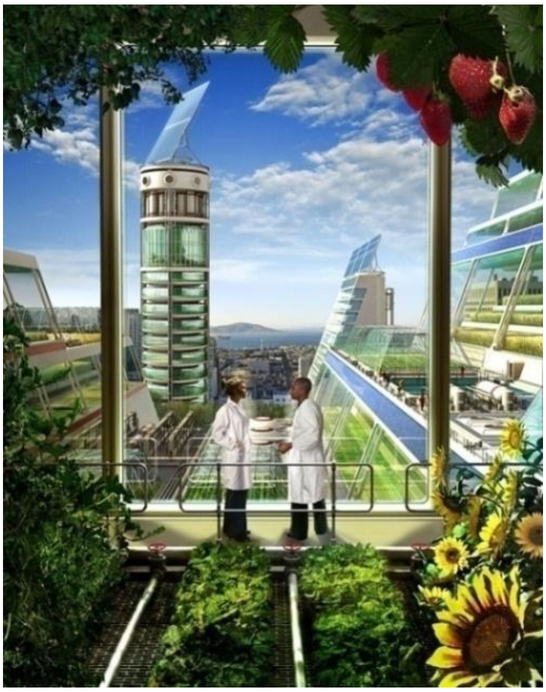


Figure 3.1 Future Farming

Vertical farms, many stories high, will be suited to the heart of the world's urban centers. If it is successfully implemented, they offer the promise of urban sustainable food production (year-round crop production), and the eventual repair of ecosystems that have been sacrificed for horizontal farming (http://www.verticalfarm.com/, retrieved February 14, 2012).

3.1. Definition of Vertical Farming:

Vertical farming is a proposed agriculture technique involving large scale agriculture in urban high-rises or farm- scrapers within a city (Wikipedia, February, 2012), farming fruit, vegetables, and grains inside of a building where different floors have different purposes (Al-Chalabi, 2009), using recycled resources, and greenhouse methods such as hydroponics, and aeroponic system, artificial sunlight, and other available technologies.

Vertical farming is a concept that argues that it is economically and environmentally viable to cultivate plant or animal life within skyscraper, or on vertically inclined surfaces (Wikipedia, February, 2012).

3.2. Origin of Vertical Farm Concept:

The concept of vertical farms has been in existence for centuries. The hanging gardens of Babylon are probably the earliest example of vertical gardening.

The Hanging Gardens were one of the greatest achievements of vertical gardening in the ancient times, built by The Chaldean King around (600) BC to please his wife who was homesick. It was an immense project because he had to import new plants that were not native to the area. The king planted many levels in the garden to replicate his gardens in the homeland. They used a simple irrigation system (chain pump) that transported water by using buckets to higher levels of the garden to water the plants (Binabid, 2010).

Also, Indigenous people in South America have long used vertically layered growing techniques, and the rice terraces of East Asia follow a similar principle (Kretschmer and Knollenberg, 2011).

Figure 3.2 Hanging Gardens of Babylon
Source:http://hydroponicsguides.files.wordpress.com, retrieved March 21, 2012

Figure 3.3 Rice terraces of east Asia
Source: http://lh6.ggpht.com, retrieved March 21, 2012

Irrespective of their origins, there are *four classification* of vertical farm origin concept:

1- First category, "Vertical Farming" by Gilbert Ellis Bailey, in 1915:

The first category of vertical farming was established, nearly a century ago, in 1915 by Gilbert Ellis Bailey, who also coined the phrase "Vertical Farming". In his book **"Vertical Farming",** Bailey defined the earliest meanings and methods of vertical farming as: "the keynote of a new agriculture that has come to stay, for inexpensive explosives enable the farmer to farm deeper, to go down to increase area, and to secure larger crops. Instead of spreading out over more land he concentrates on less land and becomes an intensive rather than an extensive agriculturist..." (Cornacchia, 2011)

2- Second category, John Todd and Nancy Jack Todd, in 1993:

Vertical farming first was envisioned by Nancy Jack Todd and John Todd in 1993 in their book **"From Eco-Cities to Living Machines".** The concept was later expanded in 1999 by Dickson Despommier, a professor at Columbia University.

Earlier, the Todds have pioneered small-scale intensive food production system or "living machines" such as aquaculture systems, vertical farms, and bio shelters. But it is taken (30) years for these ideas to influencing mainstream design, and it moves from supermarket rooftop greenhouse to entire building dedicated to urban farming. *Figure (3.4)* illustrates a proposal of warehouse farm company in Todds book.

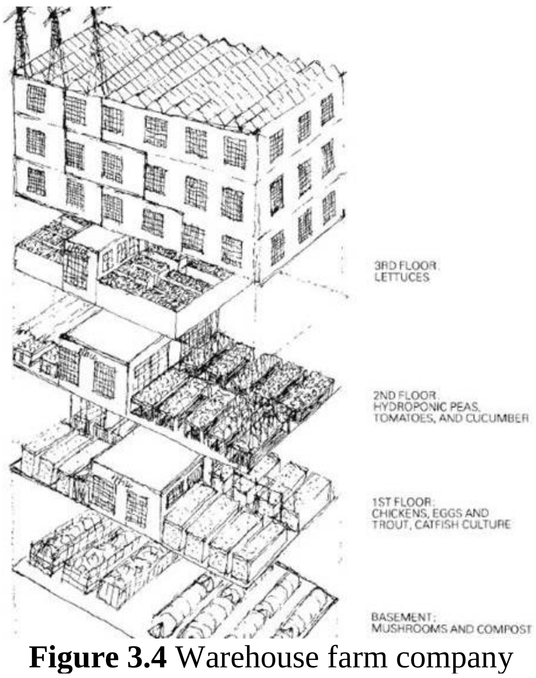


Figure 3.4 Warehouse farm company
Source: Todd N. and Todd J., 1993, p.p. 118

3- Third category, Vertical Farm of Dr. Dickson Despommier, in 1999:

The third category of vertical farming was defined by American ecologist Dr. Dickson Despommier, arguing that vertical farming is legitimate due to environmental reasons. He claims that the cultivation of plant and animal life within skyscrapers using advanced greenhouse technology such as hydroponics and aeroponics will produce less embedded energy and toxicity than plant and animal life produced on natural landscapes (Cornacchia, 2011).

According to Despommier, vertical farming thus discounts the value of natural landscape in exchange for the idea of "skyscraper as spaceship". Plant and animal life are mass-produced within hermetically sealed, artificial environments that have little to do with the outside world. In this sense, they could be built anywhere regardless of the context (Cornacchia, 2011).

4- Fourth category, Vertical Farming by Ken Yeang, 1989:

The fourth category of vertical farming denotes the concepts proposed and built by architect **Ken Yeang** developed at least ten years prior to Despommier. Yeang proposes that instead of closed mass produced agriculture structures that plant life should be cultivated within open air, mixed-use skyscrapers for climate control and consumption.

This version of vertical farming is based upon personal, or community use rather than the wholesale production and distribution of plant and animal life that aspires to feed an entire city. It therefore requires less of an initial investment than Despommier's proposed vision (Cornacchia, 2011).

3.3. Architectural Precedents of Vertical Farms:

The idea of locating agriculture in on around the cities takes on nowadays many characteristics. The idea is not new. This manner of croplands adaption to local town's topography and urban issue is very old, coming from the wisdom of pre-urban period and antiquity. Pollution, poverty and food insecurity, generated by the beginning of industrial revolution, developed in 19th century the idea of Garden City, with a green built around the industrial town and allotment gardens in the residential districts (Mira D.D., 2011)

In the 20th century, one of the earliest visions was a drawing of a tall building with agricultural production, published in 1909 Life Magazine. Other architectural visions, touching some urban agricultural ideas, were: Le Corbusier project Immeubles- Villas (1922), Austrian proposals of Hundertwasser for urban croplands on building roofs (1970), SITE group project High-rise of homes (1972) (Mira D.D., 2011).

In order to rescue urban terrain, the concept of combining living units and opportunities for food production in skyscrapers, crystallized in some contemporary visions that have been published or built: Ken Yeang with his Bioclimatic Skyscraper Menara Mesiniaga built in 1992, Rotterdam MVRDV group with pig city-2000, and Pich Aguilera architects with Garden Towers 2001.

The latest vision of vertical farming in skyscraper is the idea of Dickson Despommier, environmental health sciences professor at Colombia University. In order to improve the urban food production, comparing the production of rooftop gardens with the possibility of growing plants indoors- vertically. In 2001, Despommier proposed the first schema of a vertical farm (Mira D.D., 2011).

The above mentioned architectural precedents of vertical farms will be discussed in more details in the following pages:

3.3.1. Vertical Homesteads (1909):

The earliest drawing of vertical farm (Vertical Homestead) was published as early as Life Magazine in 1909. It was an open air building that cultivated food for the purpose of consumption. The produced drawing features vertically stacked platforms in the middle of a farming landscape. It can be seen in Rem Koolhaas's book **"Delirious"**, he wrote" the skyscraper is a utopian device for the unlimited production of virgin sites on a metropolitan location" (http://www3.jjc.edu, retrieved February 19, 2012).

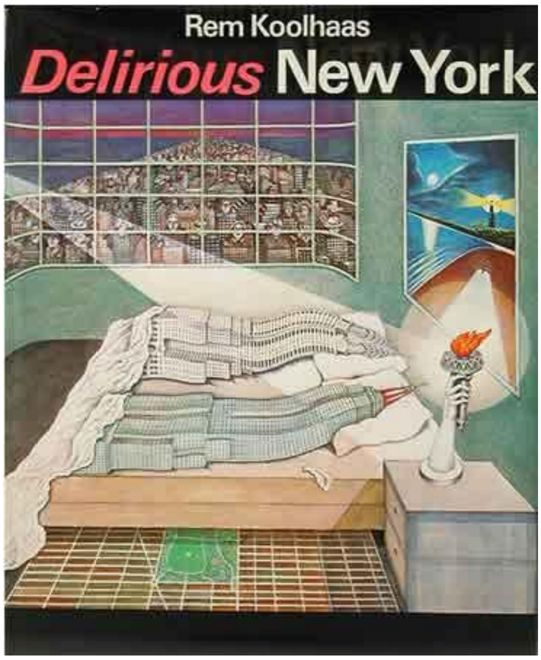


Figure 3.5 Rem Koolhaas, Delirious New York book
Source:http://architectureandurbanism.blogspot.com, retrieved February 19, 2012

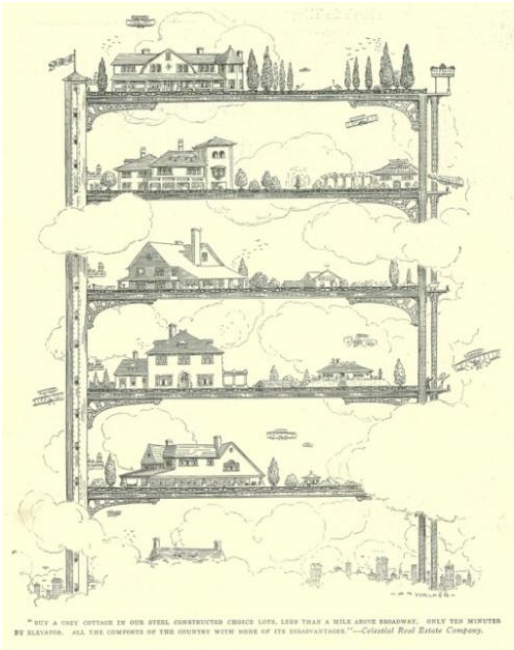


Figure 3.6 Vertical homestead

Source: http://www3.jjc.edu, retrieved February 19, 2012

3.3.2. Le Corbusier Immeubles-Villas, in 1922:

Other architectural proposals that provide the seeds for the Vertical Farm project is Le Corbusier Immeubles-Villas (Wikipedia, February, 2012).

The Immeuble Villas was an apartment building composed of multistory villas. Partly, the concept stems from Ebenezer Howard's garden city, an idea with which Le Corbusier disagreed but which he transformed into a horizontal garden city with public gardens in the center of each rectangular block and hanging gardens (the terrace) within the unit (Sherwood, 1981, p.p. 184).

(A) **Source:** (Sherwood, 1981, p.p. 184).

(B) **Source:** http://blog.naver.com, retrieved February 20, 2012.

Figure 3.7 Immeubles-Villas, 1922

Each house was an L-shaped solid and the garden a cubic void. Access is from a corridor on the courtyard side of the building. The Immeuble unit consisted of three bedrooms, living area, double-height gardens, double baths, and separate service and public corridors. The Immeuble was incompatible with an image of public housing as being economical because it could be mass-produced.

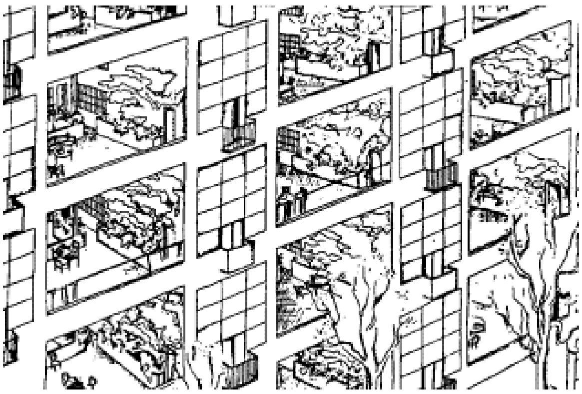


Figure 3.8 Immeubles double garden
Source: http://dlhtms.net63.net, retrieved February 20, 2012.

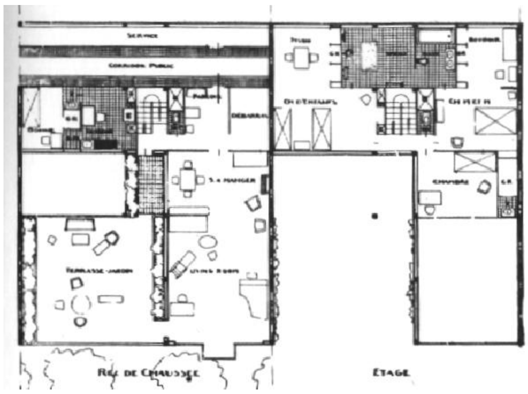


Figure 3.9 Immeubles-Villas, unit plan
Source: (Sherwood, 1981, p.p. 184).

3.3.3. The "Glass house" by John Hix, in 1950:

In the early 1950s, numerous built precedents are well documented by John Hix in his authoritative text *"the glass house"*. The *"glass house"* book traces the evolution of glass enclosures from the mid 16th century, when hostile climate led to the development of the glass house and ingenious mechanical servicing systems.

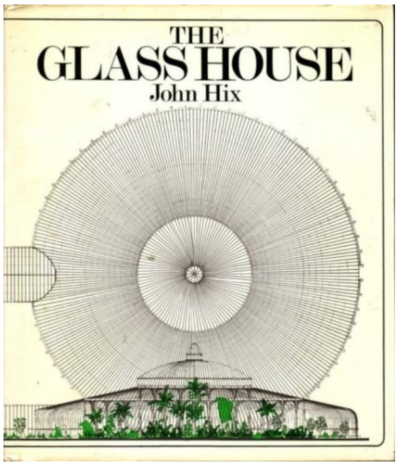


Figure 3.10 The Glass House book
Source: http://www.ebay.com, retrieved April 1, 2012

3.3.4. "Tower Hydroponicums" in Armenia, in 1951:

The Armenian tower hydroponicums are the first built example of a vertical farm, and is documented in Sholto Douglas seminal text *" Hydroponics: the Bengal system"* first published in 1951. Contemporary notions of vertical farming are predated by this early technology by more than 50 years (Wikipedia, February, 2012).

3.3.5. SITE (sculpture in the environment), High rise of homes, in 1972:

This experimental high rise housing proposal is composed of fifteen to twenty stories to be located in a densely populated urban center. The vertical community of private houses has a central elevator and mechanical core to provide services to the individual houses, gardens, and Interior Street. The philosophical motivation behind this concept is a critique of the twentieth century faceless multi-story building.

(A) Source:
http://www.architakes.com,
retrieved February 20, 2012

(B) Source:
http://bingbangpouf.files.wordpress.com,
retrieved February 20, 2012

Figure 3.11 High Rise of Home

3.3.6. Menara Mesiniaga by Ken Yeang, in 1990:

Ken Yeang is perhaps the most widely known architects that have promoted the idea of the mixed-use Bioclimatic Skyscraper which combines living units and opportunities for food production.

Figure 3.12 Menara Mesiniaga building, 1990

Source:
http://sketchup.google.com,
retrieved February 19, 2012.

The Menara Mesiniaga building was the first modern green skyscraper, it is (15) stories tall with (10) floors of office space and a vertical garden terrace up the middle (www.3.jjc.edu, retrieved February 19, 2012). Its architect, Ken Yeang, prefers to call it a "bio-climactic" building, as the way its natural ventilation strategies make the building feel as if it were breathing.

3.3.7. The Work of Dickson Despommier, in 1999:

The latest version of these ideas is Dickson Despommier's "The Vertical Farm" who is considered to be the Father of the Vertical Farm concept. Despommier's students calculated that a single 30-story vertical farm could feed some (50,000) people. And, theoretically, (160) of these structures could provide all of New York with food year-round (Kretschmer and Kollenberg, July, 2011).

By 2001 the first outline of a vertical farm was introduced by Dr. Despommier and his students, and today scientists, architects, and investors worldwide are working together to make the concept of vertical farming a reality (http://askville.amazon.com, retrieved February 25, 2012).

3.4. Advantages of Vertical Farming:

Many benefits of vertical farming are obtained from scaling up hydroponic or aeroponic growing methods, others relates to vertical farming building designs that would allow the use of renewable energy sources, and the recycling of materials of production such as water...etc.

1. Year-round crop production:

Unlike traditional farming, indoor farming can produce crops year-round, and maximize crop production takes place over an annual growth cycle as it is totally separated from the climate and local weather conditions outside (Despommier, 2010).

All seasons farming multiplies the production of the farmed surface by a factor of (4 to 6), depending on the crops (i.e. strawberries: 1 indoor acre = 30 outdoors acres) (http://en.wikiversity.org, retrieved February 28, 2012).

2. No weather-related crop failures:

Because it provides a controlled environment, the productivity of vertical farms would be independent of weather and protected from extreme weather events such as earthquakes, monsoons, tornadoes, flood…etc. (http://en.wikiversity.org, retrieved February 28, 2012).

3. No use of pesticides, herbicides, or fertilizers:

The controlled growing environment and recycling reduces the need of pesticides, herbicides, and fertilizers, advocates claim that producing organic crops in vertical

farms is practical and the most likely production and marketing strategy (http://en.wikiversity.org, retrieved February 28, 2012).

4. No agricultural runoff:

Runoff in most advanced farming operation is mixed with silt, fertilizer, pesticides, and herbicides which usually end up in some river, and destroy the wildlife ecosystem (Despommier, 2010, p.p.151). On the opposite, vertical farming virtually eliminates agricultural runoff by recycling black water. (http://www.verticalfarm.com/more, retrieved May 26, 2012)

5. Allowance for ecosystem restoration:

Vertical farming could reduce the need for new farmland due to overpopulation, and avoid the consequences of agricultural encroachment such as deforestation. VF also creates the opportunity of returning land back to nature, and restoring ecosystem functions and services (Despommier, 2010).

6. Halting mass extinction:

Traditional agriculture is highly disruptive to wild animal populations that live in and around farmland and may become unethical when there is a viable alternative. One study estimates that (10) animals killed per hectare each year with conventional farming. In comparison, vertical farming may be the only way to restore enough land for animal habitat to prevent extinction while continuing to sustain large human population (http://en.wikiversity.org, retrieved February 28, 2012).

7. Greatly reduced food miles and the use of fossil fuels:

Growing food close to home will decrease significantly the amount of fossil fuels needed to deliver them to the consumer. Producing food indoors reduces or eliminates conventional plowing, planting, and harvesting by farm machinery powered by fossil fuels. As a result, burning less fossil fuel would reduce air pollution and the carbon dioxide emissions that cause climate change (Despommier, 2004).

8. Water Recycling:

Humans already use more than half of all accessible, renewable fresh water, and 70-80% of that is used for modern agriculture, more than any other human activity (Despommier, 2004).

Vertical farming would use less water than traditional farming (less 70 % than outdoor farming), because water recycling is more practical and economic in a controlled agricultural environment (Despommier, 2010).

9. New Employment Opportunities:

Moreover, the industry of vertical farming will provide employment within urban centers, and this may help to displace the unemployment created by the dismantling of the traditional farm (Despommier, 2004). In 2030, it is expected that the vertical farmer could be one of the most popular jobs in the world (Nusca, January, 2010).

10. Educational Purpose:

Although it is fully-automated, vertical farms can also act as important education centers, allowing students and citizens to gain sophisticated training in plant growth and

technology. Without education, sustainable agriculture cannot be maintained in any location (Singhal, 2009).

11. Impacts on human health:

Traditional farming takes many particular risks on the health of labors, these include: exposure to infectious diseases such as malaria, exposure to toxic chemicals as pesticides and fungicides, and the severe injuries that can occur when using large industrial farming equipment. Conversely, vertical farming will eliminates them altogether because the environment is strictly controlled and predictable (Despommier, 2004).

12. Social Benefits:

Vertical farm could become important learning center for generations of city dwellers demonstrating our intimate connectedness to the rest of the world by mimicking the nutrient cycles that once again take place in the world that has re-emerged around them (Despommier, 2004).

13. Waste Management:

The vertical farm building has no material waste. All plant waste from growing can be collected, then burned as biomass, and create methane gas which can be used to create power for the building. The leftovers can be incorporated into nutrients for the next generation of crops (http://sustainablecitiescollective.com/tcaine/18980/new-wave-agriculture-vertical farms-101 , retrieved February 14, 2012).

3.5. Vertical farms Examples Worldwide:

Vertical farming remains as utopian visionary concept until a professor of environmental sciences and microbiology at Columbia University, Dr. Dickson Despommier, claims that he can feed (50,000) through a new form of farming.

The professor formed the idea when he and his students calculated that rooftop gardening would not successfully feed a certain quota of New York City dwellers, then, he suggested stacking gardens in levels to increase production. Now Despommier's idea has attracted several expressions of interest from international countries, engineering firms, and governmental organization (Chung, 2010).

3.5.1. Vertical Farming Examples: INTERNATIONAL LEVEL

Today many developers, investors, local governments and city planners have become advocates and have indicated a strong desire to actually build a prototype high rise farm. There has been a response from most major cities around the world, all grappling with varied solutions in terms of different agricultural forms.

The following cities have expressed serious interest in establishing a vertical farm: Incheon (South Korea), Abu Dhabi (United Arab Emirates), Dubai (United Arab Emirates), Dongtan (China), Shanghai (China), Beijing (China), New York City (United States), Portland (United States), Los Angeles (United States), Las Vegas (United States), Seattle (United States), Surrey (Canada), Toronto (Canada), Paris (France), and Bangalore (India). In addition, the Illinois Institute of Technology is now establishing a detailed plan for Chicago (Cornacchia, 2011). In the following *Figure (3.13)* is a Worldwide Map of proposed Vertical Farm projects.

Figure 3.13 Distribution of Vertical Farms in different cities worldwide
source: (the author)

3.5.1.1. Current trends and practices:

Two year ago, no vertical farms existed. Now, the modestly sized vertical farms are springing up around the world. There are in Japan, Korea, Holland, and England, and at least two more are under planning and fund-raising stages in the United States (Despommier, 2010, p.p.269). In the following there are some examples these small-scale vertical farm buildings.

- **Plant Vertical Farm in Chicago:**

The Plant is (93,500) sq. ft.; it is a retired meatpacking facility in the City of Chicago converted into a net- zero energy Vertical Farm. One-third of the Plant will hold aquaponic growing systems and the other two-thirds will have sustainable food businesses by offering low rent, low energy costs, and a licensed shared kitchen to service guests who tour the facility (http://www3.jjc.edu, retrieved April 17, 2012).

Figure 3.14 Plant vertical farm, Chicago, **Source:** http://rooftopgarden.com, retrieved on February 20, 2012

Photo 3.1 Plant vertical farm, Chicago, **Source:** http://alphafarm.org, retrieved on February 20, 2012

- **Nuvege in Kyoto Japan:**

Nuvege is a four story vertical farm, and it is privately owned and operated. It employs hydroponic and light- emitting diodes (LED) lighting system and produce leafy green vegetables. Most of the production schemes are automated (Despommier, 2010, p.p.205).

Photo 3.2 Nuvege Vertical farm

Photo 3.3 Inside Japanese Hangar Farm

Source: http://www3.jjc.edu, retrieved February 20, 2012

- **Plant Lab in Netherlands:**

Plant Lab is in Den Bosch, the Netherlands. It is privately owned and operated. One of its unique features is that it is located underground. It will produce leafy green vegetables, peppers, cucumbers, and other varieties of produce. Plant lap employs LED lighting and is highly automated.

Photo 3.4 Inside the Plant Lab in Netherlands

Photo 3.5 Plant Lab in Netherlands

Source: http://www3.jjc.edu, retrieved February 20, 2012

- **Vertical farm Suwon, Korea**

The vertical farm owned and operated by the republic of koura, it was opened in March of 2011. The building is three stories tall, features LED lighting, and all the hydroponic grow systems are highly automated. It produces leafy green vegetables.

Photo 3.6 Suwon Vertical Farm

Photo 3.7 Hydroponic system Suwon vertical farm

Source: http://www3.jjc.edu, retrieved February 20, 2012

From the above examples of Vertical Farms, it is obvious how the architects, urban planners, local authorities and municipalities try to erect such projects in their cities, even in small scale. Also, there are many large scale projects of Vertical Farm; some are still as concept, while others are under construction. The following pages will show some of these projects.

3.5.1.2. Architectural Implications of Vertical Farm Design:

As international interest grows, schematic designs are being developed globally at all levels of the architectural industry, from students to established firms. Designers are attempting to satisfy the programmatic requirements whilst creating new and interesting architectural forms (Hartany and Angelina, 2009)

Many architects have brought to light their thoughts and come up with some type of Vertical Farm model. The following *Table (3.1)* shows comparison between different Vertical farms projects in Location, Area, Cost, and Feed people.

Table 3.1 Vertical Farm Projects Comparison, sorted from the oldest to the newest:

Projects	**(A) Circular Farm Shell**	**(B) Sky Farm**	**(C) The living tower**
Architect	Chris Jacobs	Gordon Graff	Pierre Sartoux, SOA architects
Year	**2006**	**2007**	**2007**
Location	Las Vegas, USA	Toronto, Canada	Rennes, France
Height	30 stories	58 stories	30 floors
Area	-----	Floor area: 2.7 million sq.ft growing area : 8 million sq.ft	Total area : 50 470 sq. m 7000 m^2\ floor
Cost	$ 200 million	$ 110 million	$ 122 million
Feed people	72,000 people for a year	35,000 people per year	-----
Vertical Farm Picture			
Design features	▪ The first vertical farm design Grow everything from apples to winter squash. ▪ The farm could potentially make up to $25 million a year, plus $15 million in potential tourist revenue. ▪ Grow about 100 different crops. **Source:** (http://www3.jjc.edu, retrieved February 20, 2012)	▪ Graff concentrates on one form of hydroponic system, a drum system like the Omega Garden. ▪ Anaerobic digesters are used to produce methane gas, which then runs General Electric generators in building. **Source:** (http://www.treehugger.com, retrieved February 15, 2012)	▪ The concept of Living Tower aim is to associate the agricultural production, dwelling and activities in a single and vertical system. ▪ Renewable Energy: photovoltaic panels on façade, solar hot water on roof, and a wind factory of 2 wind mill on roof. **Source:** (la tour vivant, SOA architect)
Projects	**(D) Center for Urban Agriculture**	**(E) Eco-Laboratory**	**(F) Clepsydra urban farm**
Architect	Mithun	Weber Thompson	**Bruno Vigano and Florecia Costa**
Year	**2007**	**2008**	**2008**
Location	Seattle, USA	Seattle, USA	China
Height	23 floors	10 floors	10 floors
Area	----	----	1500 sq. ft footprint
Feed people	450 thousand people annually	----	----
Vertical Farm Picture			

Design features	▪ Food, water, and energy are the focus of the “Center for Urban Agriculture” design. ▪ Self- sufficient urban farm that will grow both vegetables and chickens for local consumption. ▪ Match 100 percent of the building's energy consumption. **source**: (http://rathausartprojects.com/ blog/2008/11/25/center-for-urban-agriculture-by-mithun/, retrieved February 21, 2012)	▪ A combination of a laboratory, housing, and farming. ▪ Vertical farm is complete with hydroponic grow areas, grey water remediation, research facilities, living quarters, retail space, and a learning center for children. ▪ The facility is powered by passive solar, fuel cells, solar panels, earth tubes, bio-fuels and wind turbines. **source**: (http://www.thedailygreen.com, retrieved February 21, 2012)	▪ Prefabricated structural frame needing no welding, enable fast mounting disassembling and maintenance operation. ▪ The enclosure is made of a transparent resistant structural plastic membrane (ETFE). **source**: (http://inspirationgreen.com/vertical-farms.html, retrieved February 21, 2012)

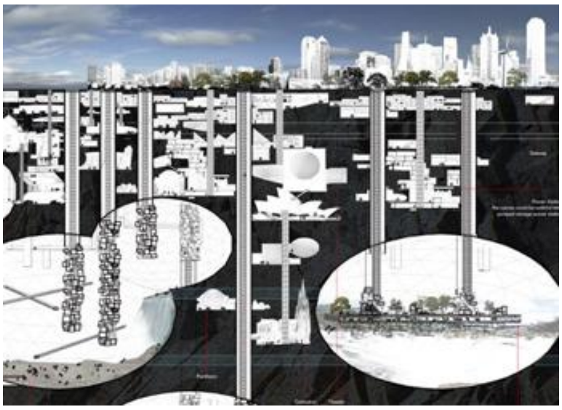
Projects	**(G) EDITT Tower**	**(H)** VF Type 0
Architect	TR Hamzah Yeang	Oliver foster
Year	2009	----
Location	Singapore	Queensland, UK
Height	26 story tower	14 floors
Area	Over half its surface area covered by organic local vegetation.	----
Feed people	----	6000 people\year
Vertical Farm Picture		
Design features	**EDITT Tower** "ecological design in the tropics". ▪ Solar panels will generate up to 40% of the building’s energy demands. ▪ Human waste will also be converted into an energy source via an on-site bio-gas facility. ▪ The building is constructed of recyclable materials. **Source:** http://jennajasso.com/vertical-farming, retrieved February 21, 2012	▪ Site selection based on close proximity to food outlets, for distribution. ▪ Program: Farming, Orchards, Restaurants, Cafe and Educational Facilities. ▪ Aim is to feed 6000 people on a vegetarian diet plus fish. **Source:** http://www.brianschmidt.com/thesis/brian_vf.pdf, retrieved February 21, 2012

3.5.1.3. Alternative Architectural Design:

Vertical farm architectural proposals have taken many different forms and shapes, express different designer intentions. The following *Table (3.2)* illustrates some of these concepts.

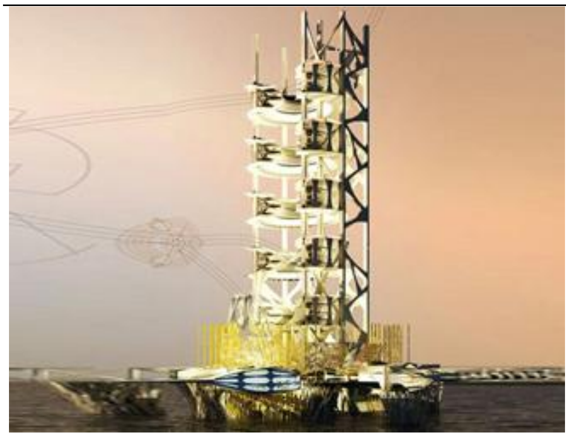
Table 3.2 Other Vertical Farm Proposals:

 (A) Conventional, Stacked Horizontally	 (B) Diagonally Stacked
 (C) Paris Pyramid, by Herzog and de Meuron	 (D) Open Air Tower, by Blake Kurasek
 (E) Dome, The Plantagon	 (F) Domes built over roadways, bio-mimicry of a Termite Mound.



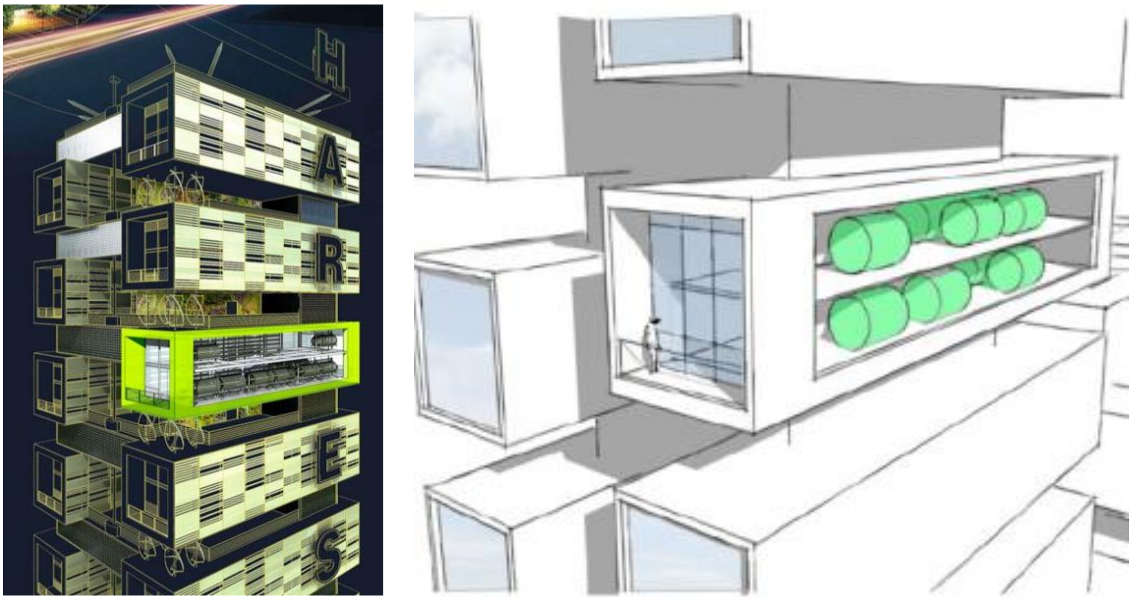
(G) Upside Down, Underground Vertical farm

(I) Scaffolding, This design utilizes sky walks between pods.



(J) Repurposed Oil Rig, by Rewan Fernando, Five stacked u-shaped structures

(K) Eco-pods or prefabricated module, by Howeler and Yoon Architecture
Source: http://jennajasso.com, retrieved February 20, 2012



(L,M) Harvest Green project in Vancouver, by Romses architects, The growing modules use circular containers to grow the food.
Source: http://www3.jjc.edu, retrieved on February 20, 2012

3.5.1.4. Eco-laboratory by Weber Thompson / 2008: Case study analysis

- **Background of the project**

It is a collaborative effort of Weber Thompson architects in Seattle; which won the natural design Talent competition in 2008. The Eco-laboratory is a combination of a laboratory, housing, and of course farming.

Figure 3.15 Eco-laboratory Vertical Farm, Seattle
Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

- **Concept:**

There is no "silver bullet" for sustainability. There is no "magical solution" to create beautiful net-zero energy and net-zero water consumption environments. Recognizing a living building's dependence on multiple systems, eco- laboratory is synergy of economics, culture and environment working together in harmony.

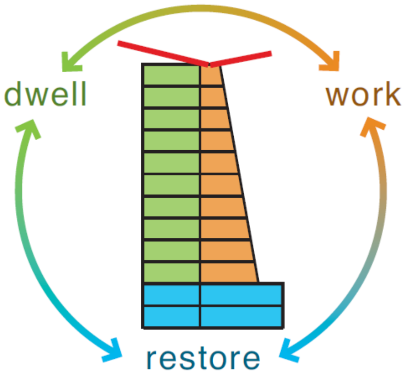


Figure 3.16 Eco-laboratory functioning concept
Source: Weber Thompson, 2008

- **Building program:**

Eco-laboratory creates mixed-use concept with farming, dwelling units, a community garden, and a neighborhood market.

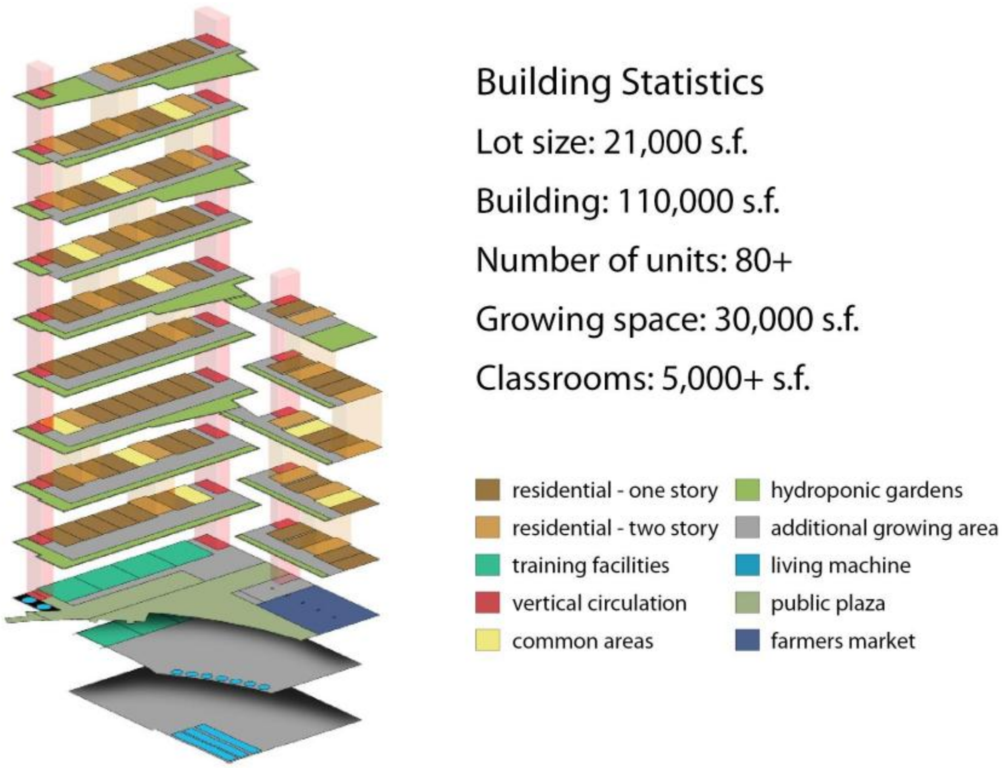


Figure 3.17 Building Program Analysis
Source: Weber Thompson, 2008

- **The Living Building Challenge of Eco-laboratory:**

It requires attention to six petals of prerequisites, and they are:

1. Site:

Eco-laboratory fills the block with an expanded garden behind three original working class cottages, sits at the corner of Elliot Avenue and Vine Street in downtown Seattle's Belltown neighborhood.

Figure 3.18 Site Location

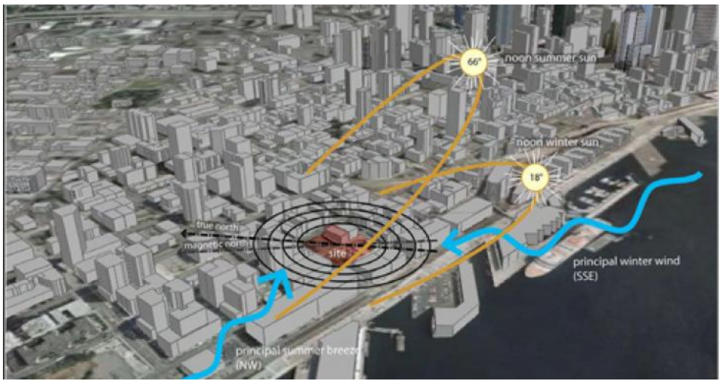


Figure 3.19 Site Context

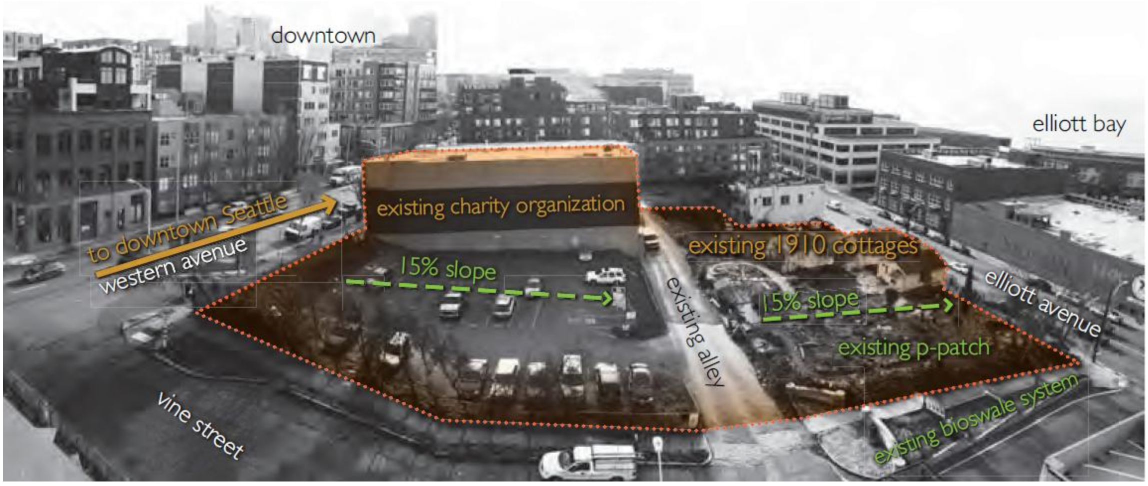


Figure 3.20 Site Analysis
Source: Weber Thompson, 2008

2. **Materials** issues are addressed by reclaiming locally discarded shipping containers and using them in the main living unit module.
3. **Water** is collected through impervious surfaces and introduced in a carefully balanced cycle in which a living machine converts black water to grey water and potable water
4. **Energy** has two approaches: passive conservation channels to drive stack-effect thermal control, and active harnessing of solar, wind, bio fuel, and hydrogen fuel forces to generate electrical power.
5. **Indoor quality** is integrated with passive energy strategies. Earth tubes draw in fresh air from the site up and through indoor occupied spaces
6. **Beauty and inspiration** are not only found in aesthetics of form, but in the aesthetics of performance through the experience of place and lasting value for visitor and residents.

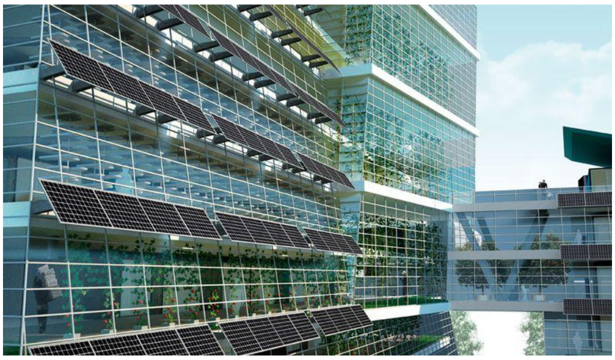


Figure 3.21 Hydroponic system and PV panels

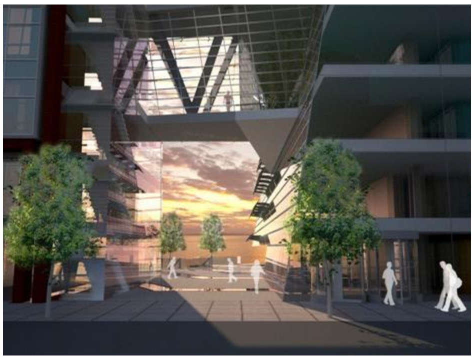


Figure 3.22 Eco-laboratory public entry

Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

- **Ventilation, Water and Energy cycle of Eco-laboratory building:**

1. Building Ventilation:

Building ventilation can customize the variation of temperatures for different crops through mechanical louvers. The system starts outside capturing fresh air from the garden, and forces that air into the building. The cool air is pumped up from the bottom exhausting the hot air out of the top. Vents can be closed to keep the temperature warm for tomatoes for instance that prefer the hotter climates.

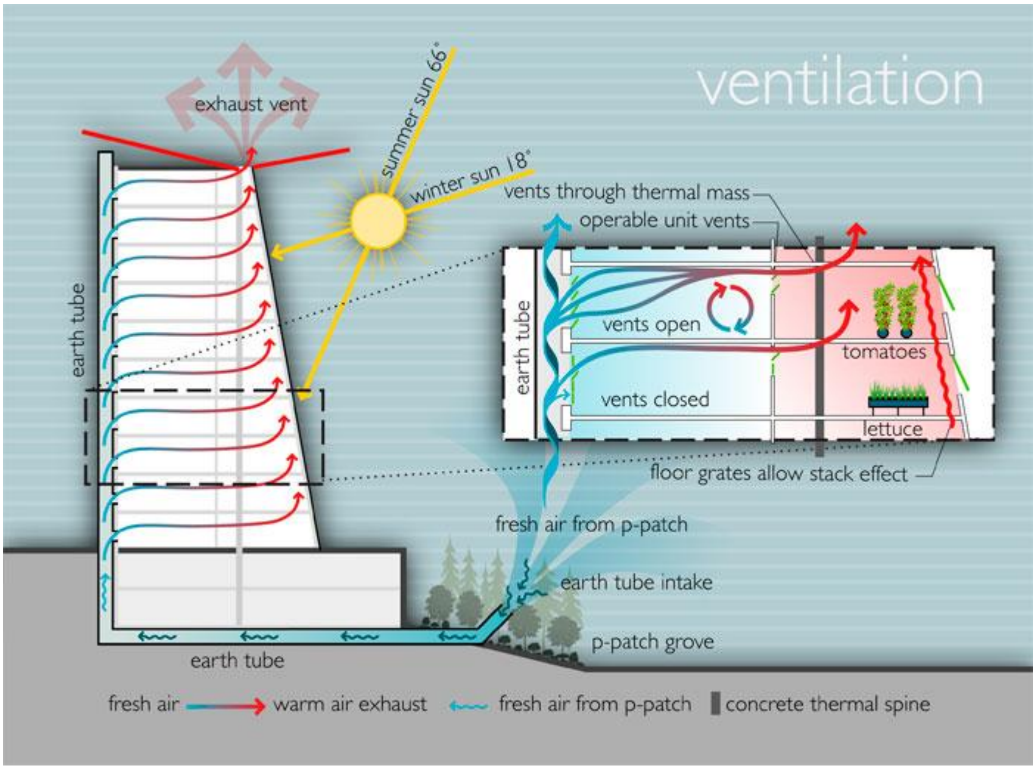


Figure 3.23 Building Ventilation of Eco-laboratory

Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

2. Water Cycle:

The shape of the roof was designed in a shape to best capture rainwater. The rainwater is then used for all of the housing units. Once used both grey and black water are recycled through a waste water treatment greenhouse. The treatment water continues onto the hydroponic systems for the plants.

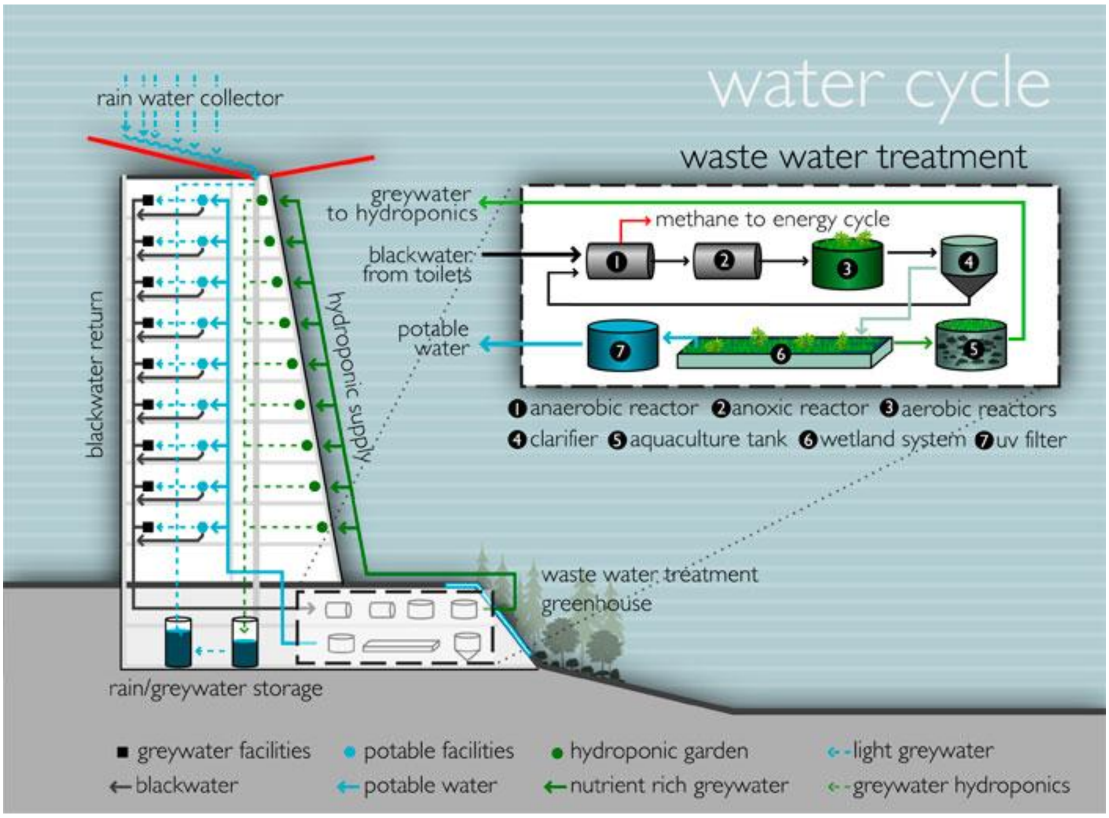


Figure 3.24 Water Cycle of Eco-laboratory building
Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

3. Energy Cycle:

In terms of energy, the laboratory tries to capture as much energy as possible from all elements. Wind turbines are located on the rooftop. Solar panels to capture the sun's rays are not only located on the roof but on the southern façade too. This building also takes methane from the plants waste.

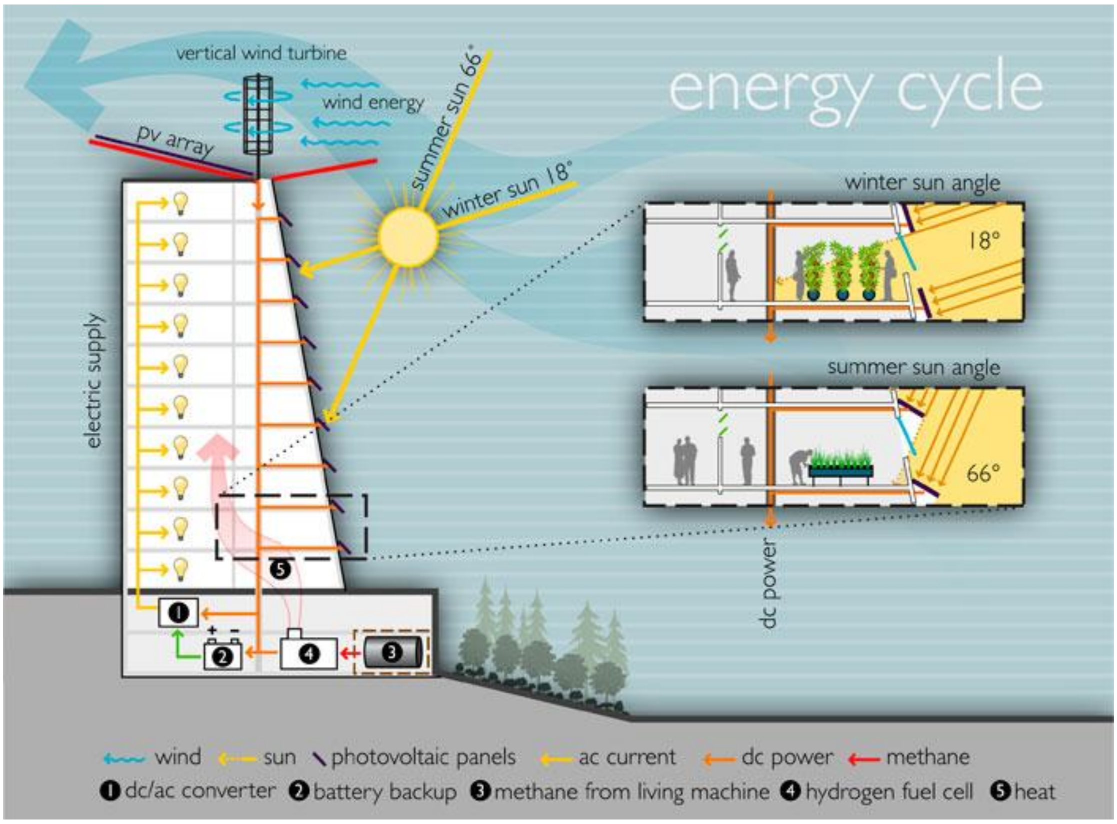


Figure 3.25 Energy Cycle of Eco-laboratory building
Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

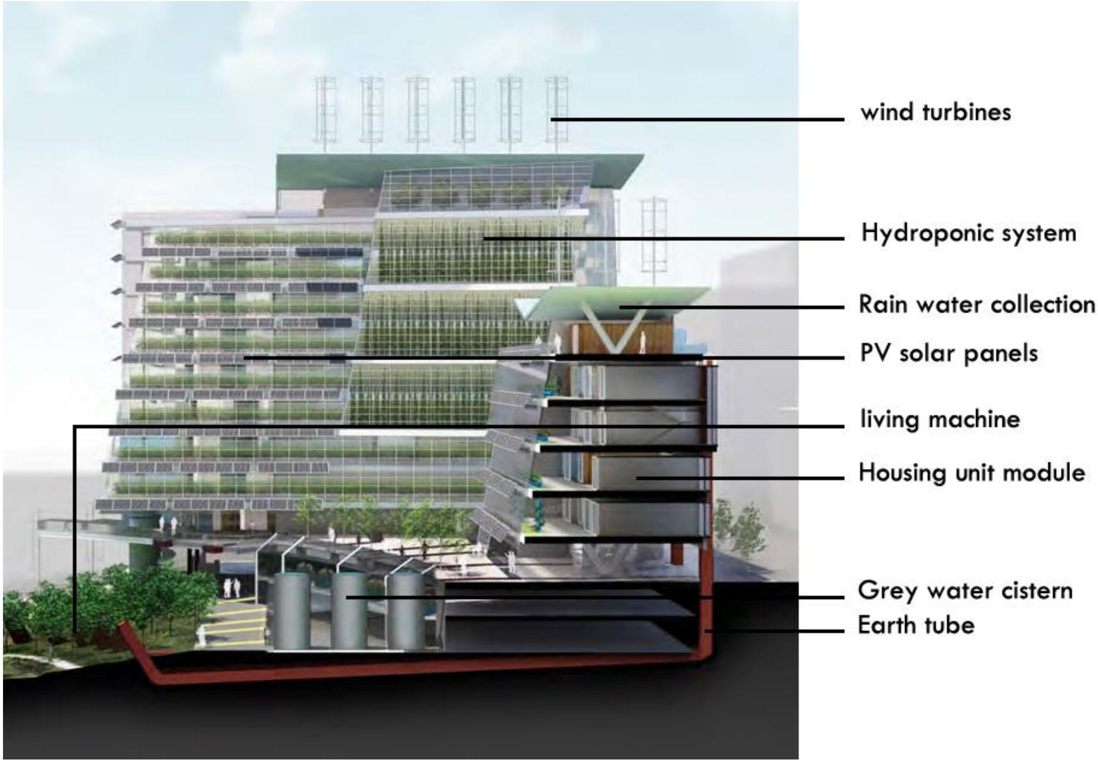


Figure 3.26 Section of Eco-laboratory building showing the main sustainable systems
Source: http://www.weberthompson.com/eco-laboratory.html, retrived April 2,2012

From eco-laboratory case study, it can be learned:

- Vertical farm building could be more than a building for farming; Eco-laboratory merges a neighborhood market, basic shelter, vocational training facility and public sustainability educational center into a financially viable downtown residential development.
- Eco-laboratory building has many features of sustainable systems such as: rainwater collection, hydroponics, living machine, grey water cistern, wind turbines, photovoltaic, earth tubes, ventilation control, bio-fuel, and thermal spine that can be involved in the design of any vertical farm.
- One of the sustainability features of Eco-laboratory design is the building site and its relation with the surrounding context. For example the construction material of Echo-laboratory is the local discarded shipping containers.
- In general, it can be concluded from the previous examples the variety shapes and forms of vertical farm building, to meet the different needs of plants and local communities. For example the u-shape, dome, pyramids and diagonally stacked are designed to capturing maximum sunlight for plant growth.

3.5.2. Vertical Farming Examples: REGIONAL LEVEL

Vertical Farm has interests not only in developed countries, but also in developing countries in the Arab World such as, Dubai, Israel, and Syria, and Abu Dhabi which analyzed in 2007 the possibility to build a Vertical Farm in the city area.

- **Israel Vertical Farm Vision:**

In the developing countries, the idea of Vertical Farming is still an imaginary event, except Israel. In 2010, the Green Zionist alliance proposed a resolution at the 36th world Zionist congress to develop Vertical Farms in Israel. Many architectural proposals are drawn for high density population cities such as Tel Aviv and Jerusalem.

Figure 3.27 Vertical Farm Competition in Jerusalem

Source: http://www.evolo.us/architecture/urban-agro structure-for-Jerusalem/, retrieved March 8, 2012

- **Dubai Vertical Farm Vision, 2009:**

The concept of developing a Vertical Farm, in Dubai, is still in the planning phase but from a logical standpoint the project makes a lot of sense, since it will supply fresh vegetables and other crops, as well as fresh water from sea recycling.

The unique design of the farm will consist of several large round, branching tree-like from a central shaft to bring cooled water inside to create humid air, then fresh water is collected in special tanks for both irrigation and drinking (Picow, 2009).

Figure 3.28 Seawater Vertical Farm in Dubai, UAE
Source:http://www.greenprophet.com, retrieved July 5, 2012

- **Syria Vertical Farm Vision:**

For the first time in its modern history, Syria had to import wheat after a serious drought in 2008, where the majority of the farmer's crops failed. In response to the alarming situation in Syria, architects James Murray and Toby LIoyd from UK proposed a series of vertical hydroponics oases which provide housing and allotments for local residents.

The structure consists of hydroponic pods which plug-in to the main structural frame, the project also counts with water collectors, purification tanks, wind turbines, and solar panels (eVolo Magazine, August, 2010).

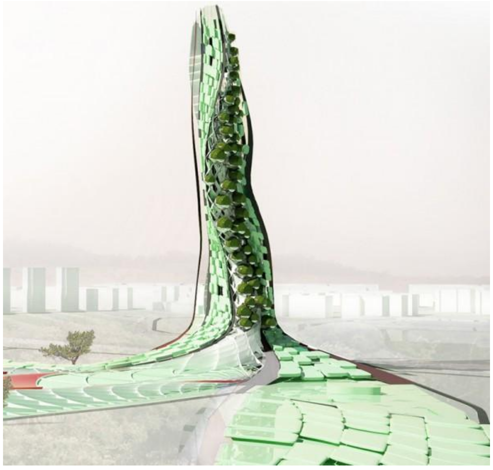


Figure 3.29 Vertical Oasis in Syria **Figure 3.30** Vertical Oasis in Syria site plan
Source: http://www.evolo.us/architecture/vertical-oasis-in-syria-is-a-hydroponic-farm/, retrieved July 5, 2012

For both International and Regional level, it is found great interests for the concept of Vertical Farm. While at local level, in Palestine, there is no obvious interest about the concept, so the research will propose the first prototype of Vertical Farm in Palestine.

In the following section, the research will introduce the main factors behind need of Vertical Farming in our country.

3.5.3. Vertical Farming on LOCAL LEVEL: West Bank, Palestine

In this section, the research will introduce necessity to adapt Vertical Farming in Palestine, through the analysis of population growth, climate change, agricultural sector, and water scarcity.

3.5.3.1. Location and area of Palestine:

Palestine consists of two main parts: the West Bank and Gaza strip. The West Bank is located to the east of Israel and the west of Jordan. The Gaza Strip is located between Israel and Egypt on the Mediterranean coast.

The total area of West Bank is 5,860 km^2, and Gaza strip is 360 km^2.

(http://www.infoplease.com/ipa/A0776421.html, retrieved March 30, 2012).

Figure 3.31 Palestine Map, **source:** http://www.ungei.org , retrieved March 30, 2012.

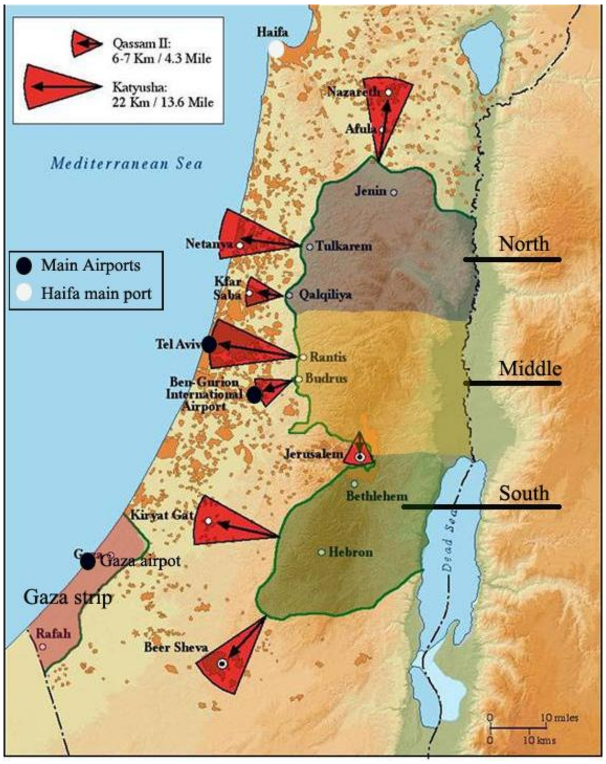
3.5.3.2. Population Growth of Palestine:

In 2012, the total population of Palestine is estimated to be 4,293,309 people, the population of West Bank is 2,649,020, while Gaza strip is 1,644,289 (PCBS, 2012).

According to PCPS assumption, Future population growth of West Bank and Gaza Strip will be up to (6) million people by 2025, as illustrated in *Appendix (1)*, while the expected number of returnees will exceed (200,000) people by 2015.

3.5.3.3. Palestine Main districts:

Palestine can be divided into four main districts, the north, middle, and south of the West Bank, and Gaza Strip,



North area:
Jenin, Tulkarem, Qalqelya, Tubas, Salfit and Nablus.

Middle area:
Rammallah, Jericho, and Jerusalem.

South area:
Bethlehem, and Hebron.

Gaza strip:
Gaza and Rafah.

Main airports:
Ben-Gurion international airport.
Tel Aviv airport
Gaza airport
Haifa main portes

Figure 3.32 Palestine Main Districts
Source: http://www.defensibleborders.org/images/map4.jpg, retrieved March 30, 2012

The potential locations of the proposed Vertical Farm building in Palestine will be determined according to specific characteristics of the previous four districts, which will be discussed in the *Chapter 5*.

3.5.3.4. Climatic Profile of Palestine:

Climatic condition of Palestine can be determined by the following climatic indicators, temperature, annual rainfall, relative humidity, wind speed, and sunshine hours; these indicators will affect the potential locations of the proposed Vertical Farm building.

- **Temperature:** It is concluded from the following *Figure (3.33)* that the highest means of air temperature are recorded in Hebron in the south of west bank, while the lowest means of air temperature are recorded in the Gaza strip.

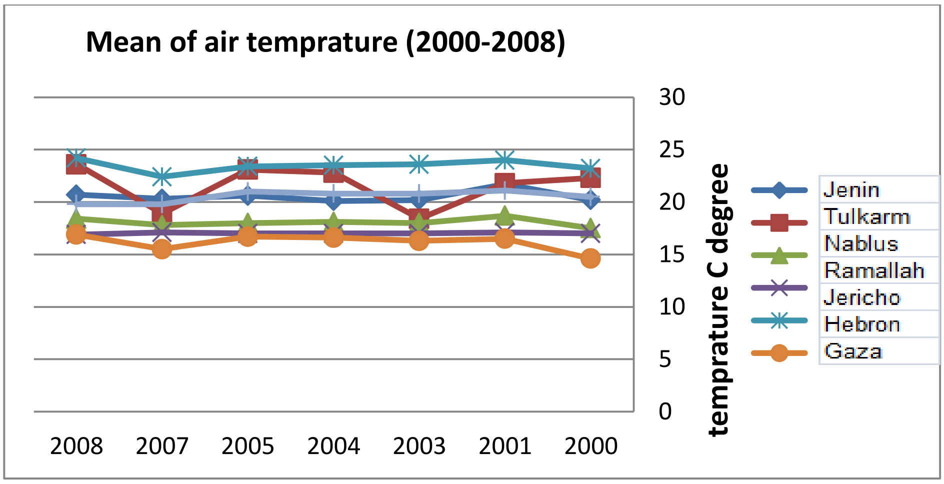


Figure 3.33 Mean of Air temperature (2000-2008)
source: (PCBS, 2008)

- **Annual rainfall:** the following *Figure (3.34)* indicates that the highest annual rainfall records are in Nablus in the north of West Bank, while the lowest records are in Jericho in the middle of West Bank.

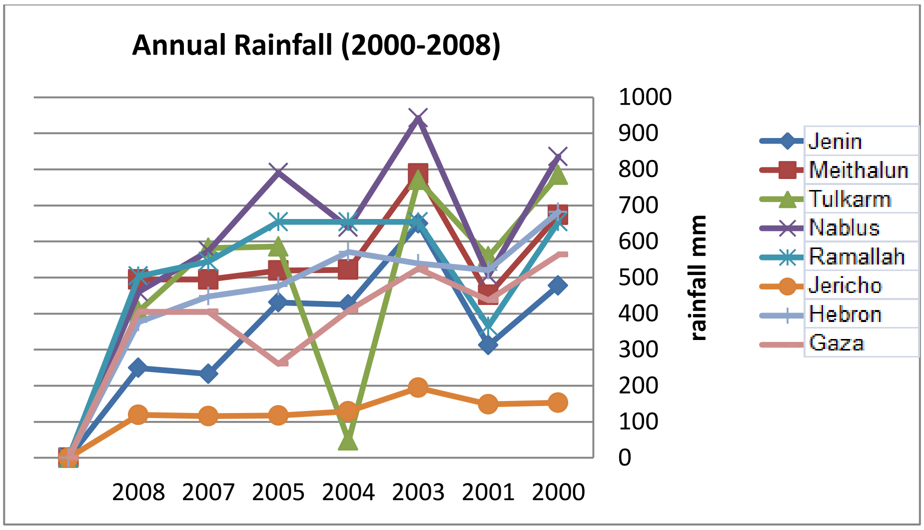


Figure 3.34 Annual Rainfall (2000-2008)
source: (PCBS, 2008)

- **Humidity:** the following *Figure (3.35)* indicates that the highest records of the average annual relative humidity are in Gaza, while Jericho has the lowest records of annual relative humidity.

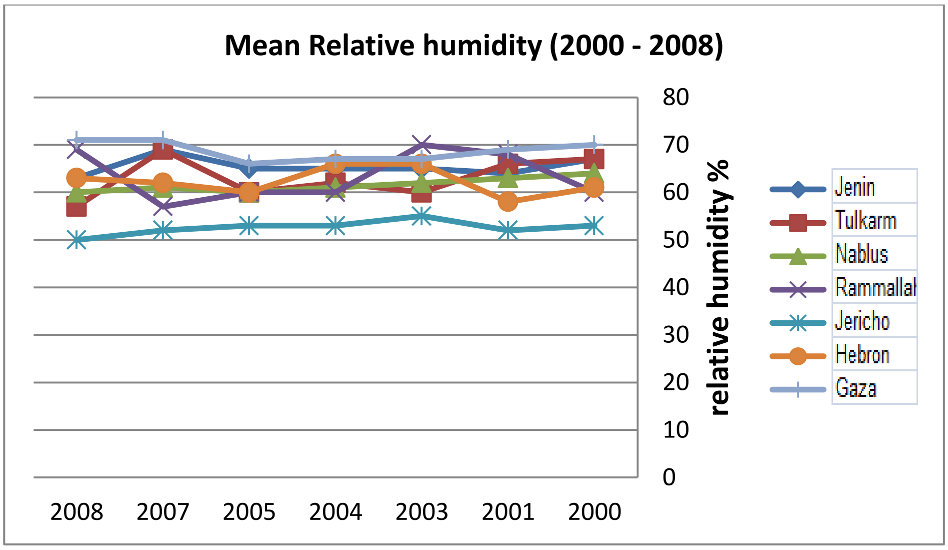


Figure 3.35 Mean of Relative Humidity (2000-2008)
source: (PCBS, 2008)

- **Wind speed:** the following *Figure (3.36)* indicates that the highest wind speed records are in Hebron and Ramallah, while the lowest records are in Tulkarm and Jenin in the north of West Bank.

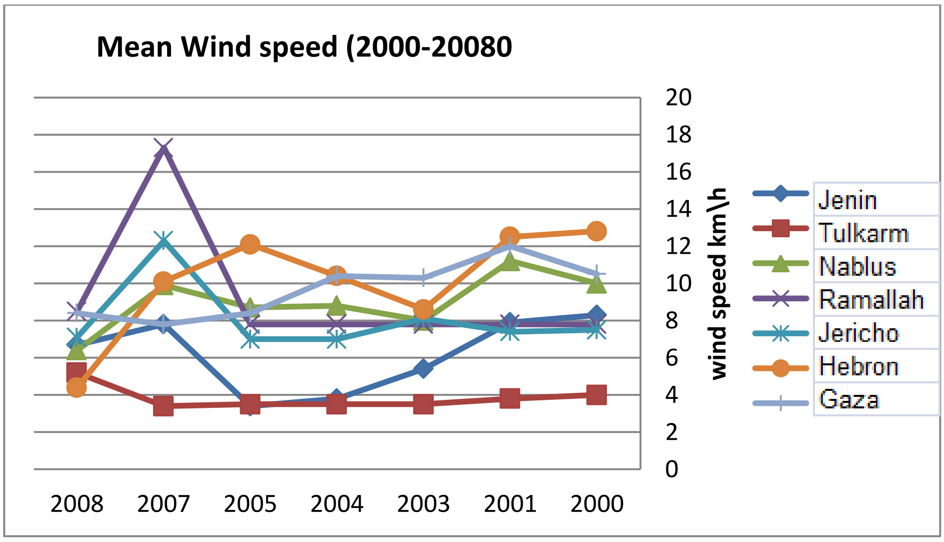


Figure 3.36 Average of Wind Speed km\h 2000-2008
source: (PCBS, 2008)

- **Sunshine hours\ day:** *Figure (3.37)* indicated that the highest duration mean of sunshine was (12.5) hour/day in Ramallah Station in June, and the lowest duration mean of sunshine was (5.1) hour/day in Ramallah Station in December.

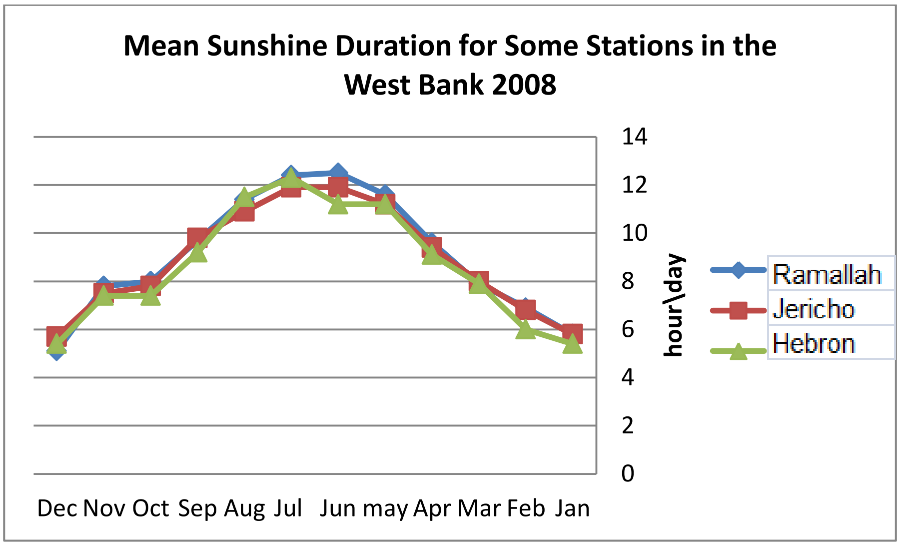


Figure 3.37 Mean Sunshine hours for some cities in West bank, 2008
source: (PCBS, 2008)

3.5.3.5. Main Agricultural Crops in Palestine:

The Palestinian territory has five agro-ecosystems: Al-Aghwar, semi-highlands, highlands, semi-costal and Costal ecosystems. These agro-ecosystems have the potential to produce up to (105) crops all around the year, including (38) types of fruit trees, (37) types of vegetables and (30) types of field crops and grains. However, ***local production is limited and unstable*** due to climatic problems and lack of access to land due to Israel restrictions (ARIJ, 2010).

In general, there are three types of crops production in Palestinian territory: field crops, fruit trees crops, and vegetables crops.

Figure (3.38) indicates that vegetable crop has the lowest percentage of cultivated areas which is 14%, while the horticulture trees have the highest percentage which is 59%.

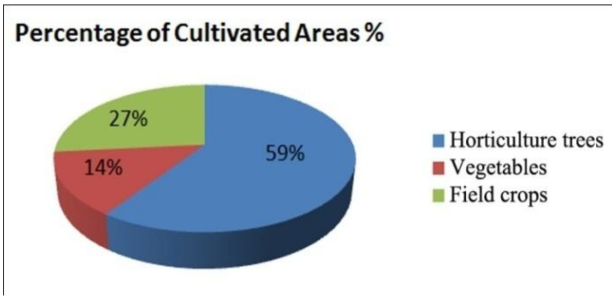


Figure 3.38 Cultivated Areas in the Palestinian territories
Source: (PCBS, 2010)

It can be concluded from *Figure (3.39)* that vegetable crop production is the most expensive production process, while it has the lowest percentage of cultivated areas.

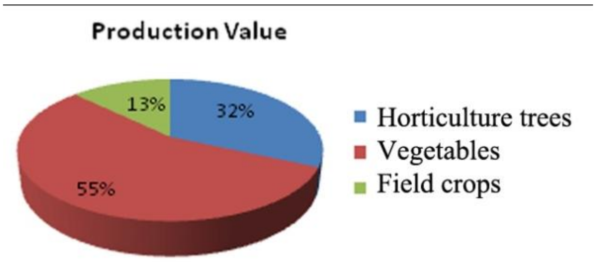


Figure 3.39 Production Value of Fruit Trees, Vegetables and Field Crops in the Palestinian Territory
Source: (PCBS, 2007\2008)

It is obvious that vegetables will be the candidate crop for the proposed Vertical Farm building, as it has the least cultivated area, and the highest value of production, besides other factors that will affect the selection of vertical farm crops, these factors will be discussed in Chapter five.

3.5.3.6. Water situation in Palestine:

Palestinian Territory is affected by limited access to water resources due to the Palestinian- Israeli conflict. This has hampered agricultural productivity and resulted in land degradation and failure to achieve food self-sufficiency (PCBS, 2012).

The total agricultural land currently used by Palestinians covers 30.5% (1834.8 km^2) of the Palestinian land area. Rain-fed agriculture is practiced in 80% of the total cultivated area, while only 19.5% is irrigated agriculture (ARIJ, 2010).

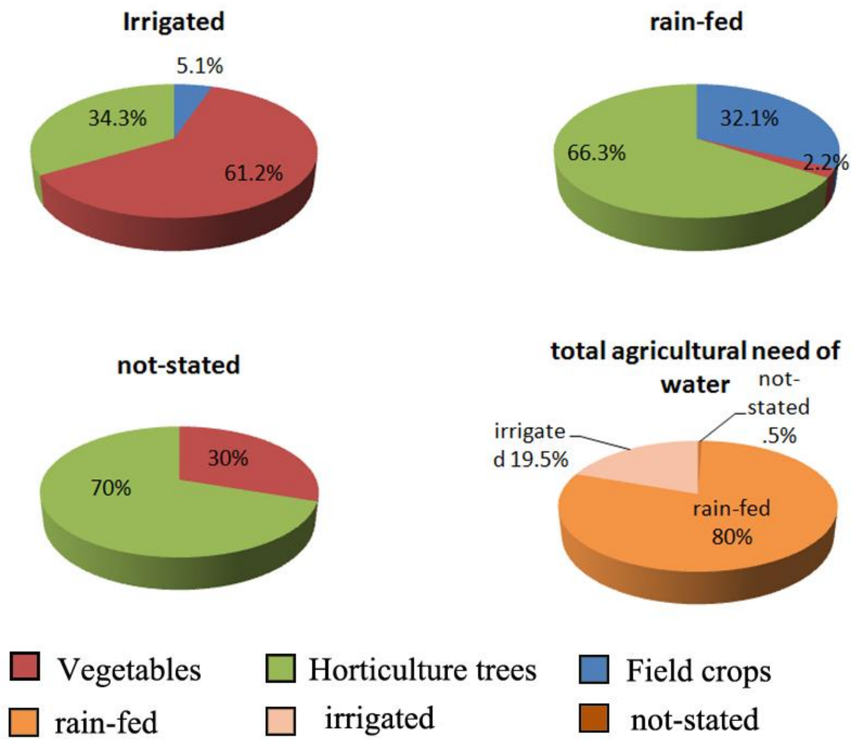


Figure 3.40 Agricultural Census-2010, Final Results- Palestinian Territories
source: (PCBS, 2011)

The present and future agricultural need in Palestine illustrated in *Appendix (1).*

It can be concluded that Vertical Farm could be the optimum solution for the previous mentioned problems in Palestine from increase of population growth, urgent need of food, water scarcity, unstable and limited local production.

CHAPTER FOUR

Applied Technologies and Devices to Vertical Farm building

Vertical farming relies on the use of various physical methods to become effective. Combining these technologies and devices in an integrated whole is necessary to make Vertical Farming a reality. All the technologies employed in Vertical Farm building are currently available and existent. This chapter will illustrate many of these technologies and devices, and some strategies of sustainable building design.

4.1. Optimizing Orientation and Building form:

(A) Building Orientation:

In solar passive building, orientation is a major design consideration, mainly with regard to solar radiation, day-lighting and wind.

Orienting the footprint of the Vertical Farm with a north-south exposure will allow designs to capture maximum amounts of light (Despommier, 2010, p.p.119).

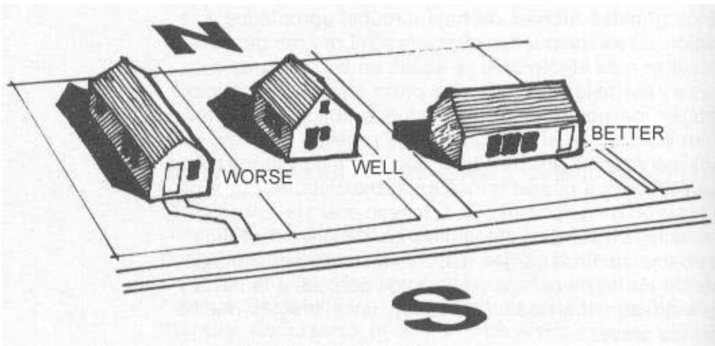


Figure 4.1 Building Orientation for maximum sunlight
Source:http://www.geocities.com/ResearchTriangle/Facility/8776/indiceE.htm, retrived May 22, 2012.

Also, the natural wind direction has to be taken to the maximum in Vertical Farm orientation. According to greenhouse orientation, the maximum dimension of greenhouse should be perpendicular to the wind direction especially in summer (Tamil Nadu Agricultural University- TANU, 2008).

(B) Building Form:

Thermal performance of the volume of a space has direct relationship with the area of the envelope enclosing that volume, this parameter known as, surface\volume ratio (S\V), which is determined by the building form *(see Figure 4.2).*

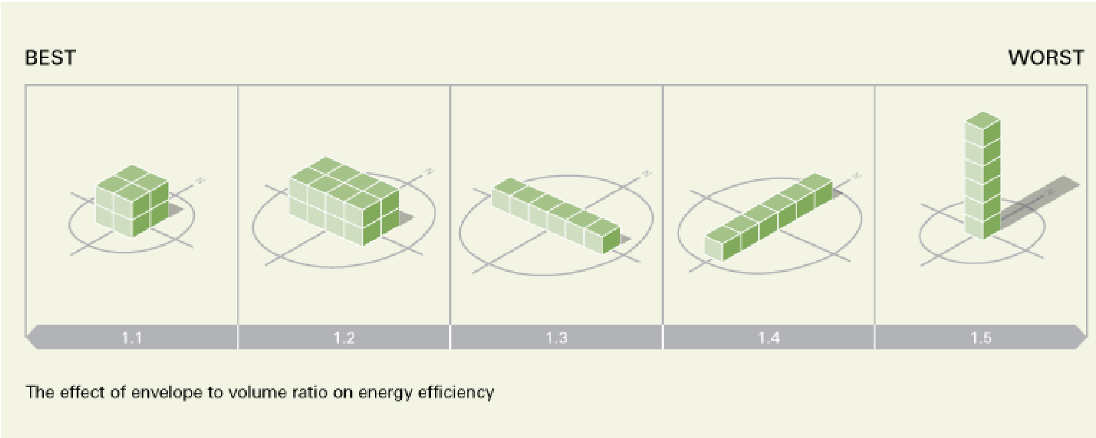


Figure 4.2 Surface\ Volume Ratio, showing the best building form,
Source: http://www.thechallengeseries.ca/wp/wp-content/uploads/2009/09/a_PD6.png, retrived May 22, 2012

The building form also determines the air flow around the building and hence the ventilation rates inside. The depth of the building determines the amount of day-lighting; the deeper building is, the more artificial light is required.

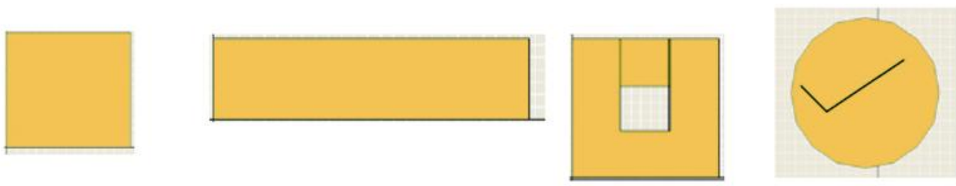


Figure 4.3 Building Forms simulated for surface to volume ratio
Source: http://www.teriin.org/ResUpdate/reep/ch_1.pdf, retrieved July 7, 2012

4.2. Day-lighting Capturing Devices and Architectural elements:

Before introduction to day-lighting capturing devices that enhance day-lighting penetration, it is important to understand window design consideration.

Usually the standard window provides daylight illumination to a depth of about (1.5) times the distance between the floor and the top of the window *(see Figure 4.4)*, and 3 to 4 times for two sided day-lighting room.

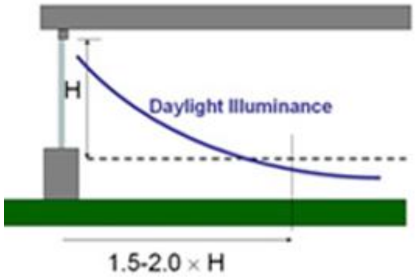


Figure 4.4 Window Design showing day lighting luminance

1) Parabolic Mirrors:

A **parabolic reflector** (or **dish** or **mirror**) is a reflective device used to collect or project energy such as light, sound, or radio waves. Its shape is that of a circular parabolic, that is, the surface generated by a parabola revolving around its axis (Wikipedia, April, 2012). It is used in building with deeper interiors, situated outside and behind the building to first concentrate, then direct sunlight to the interior section.

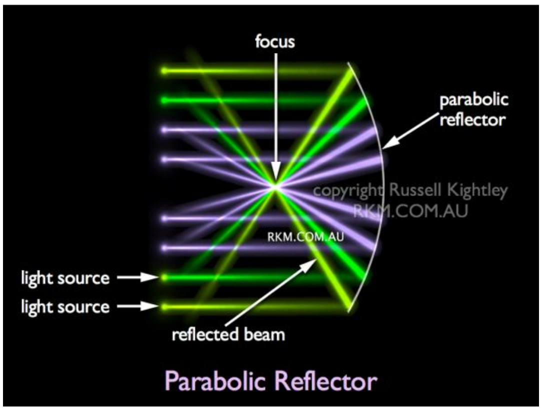


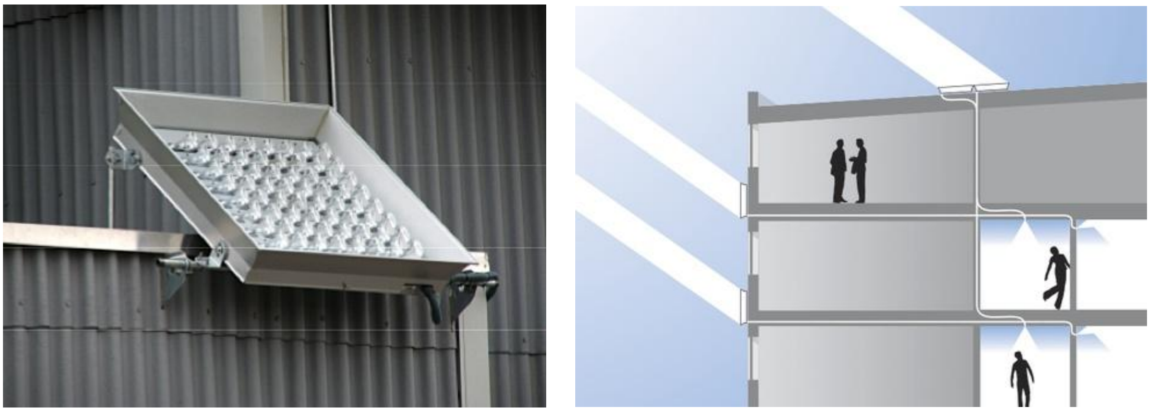
Figure 4.5 Section showing the function of Parabolic mirror
source: http://www.rkm.com.au, retrieved may 11, 2012

Figure 4.6 Parabolic Mirror
source: http://www.solarglazingmag.com.jpg, retrieved may 11, 2012

2) Fiber optics:

An **optical fiber** (or **optical fiber**) is a flexible, transparent fiber made of a pure glass (silica) not much thicker than a human hair. It functions as a waveguide, or light pipe, to transmit light between the two ends of the fiber (Wikipedia, May, 2012).

The interesting thing about fiber optic lighting is that it creates the ability to put natural light in places where there is none, by transmitting the light from outside.



(A) (B)

Figure 4.7 Fiber Optics Device
Source: http://www.jetsongreen.com, retrieved may 11, 2012

3) Light Shelf or Reflective Edge:

A **light shelf** is an architectural element that allows daylight to penetrate deep into a building. This horizontal light-reflecting overhang is placed above eye-level and has a high-reflectance upper surface. This surface is then used to reflect daylight onto the ceiling and deeper into a space (Wikipedia, April, 2012).

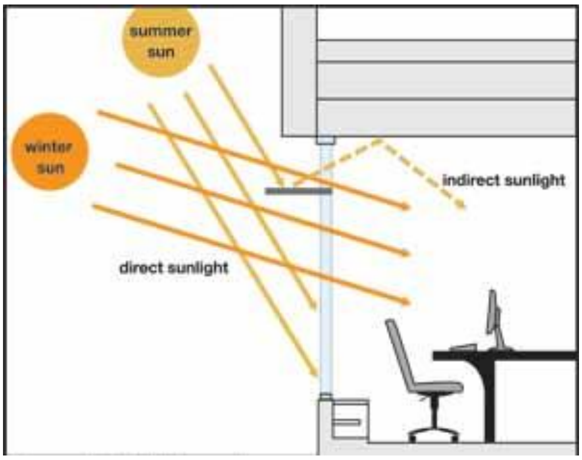


Figure 4.8 Light Shelf
Source: http://archrecord.construction.com, retrieved may 13, 2012

4) Light tube:

Light tubes or **light pipes** are used for transporting or distributing natural or artificial light. In their application to day lighting (Wikipedia, May, 2012).

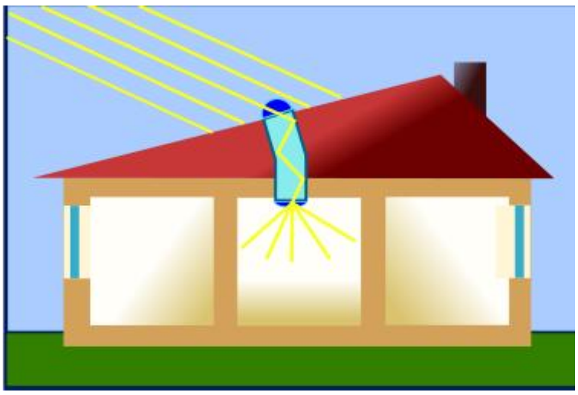


Figure 4.9 Light Tube

4.3. Artificial Lighting System:

Not all the energy in sunlight is needed to grow any crop to its maximum yield (just blue and red waves of light). We can take advantage of this fact by creating lighting exclusively for the plants by using artificial light system, such as:

(A) LED system:

Light- Emitting Diodes (LEDs) have already been specifically engineered to create light exclusively for the plants, resulting in a significant saving in energy costs (Despommier, 2010, p.p. 183-184).

(B) Organic Light Emitting Diodes (OLEDs):

On the near horizon are OLEDs made of thin, flexible plastics, it contains stable organic compound that allow narrow spectra of light to be produced, while still giving plants exactly what they need. In addition, it will permit the design of lights that could be made into any configuration, placing the light source at the optimal distance from the plant, regardless of the plant shape (Despommier, 2010, p.p. 183-184).

Photo 4.1 LED light system in greenhouse, **source:** http://www.fobsun.com, retrieved may 10, 2012

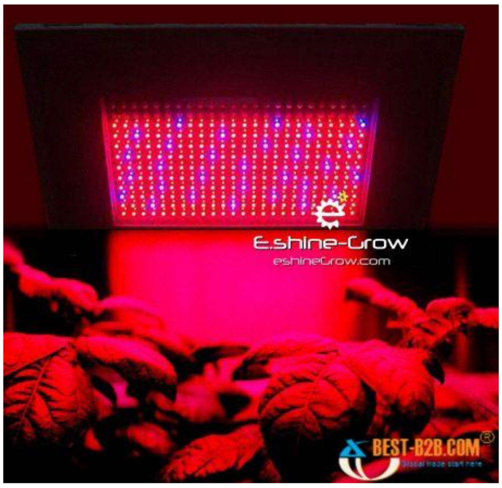


Photo 4.2 OLEDs **source:** http://www.bestb2b.com, retrieved may 10, 2012

Table 4.1 Average light coverage guide of plant growth:

Lamp (W)	250	400	600	1000
Area covered m^2	.5	1	1.5	2

Source: http://www.hydrogarden.com/what-is-hydro.asp

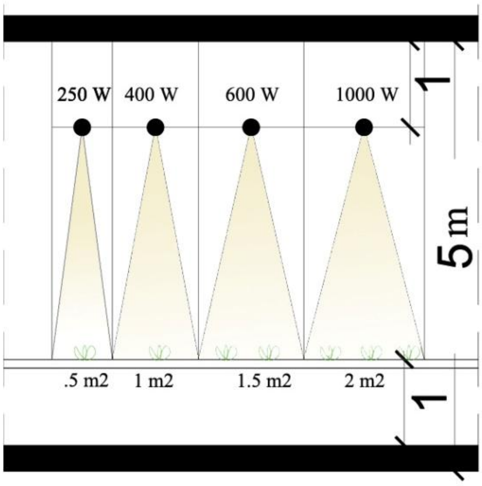


Figure 4.10 Section showing different lamp light coverage of plant growth

4.4. Natural Ventilation:

Natural ventilation systems rely on pressure to move fresh air through building, the pressure difference can be caused by wind (cross ventilation) or by temperature or humidity differences (stack effect) (Walker, 2010). In both cases, the amount of ventilation depends on the design of openings, their size and placement.

For an adequate amount of air, the area of operable windows should be 20% or more of the floor area, and the area of inlets should equal the area of outlets.

The type of window can also have a considerable effect on the path of internal air flow and its cooling value *(see Figure 4.11)*

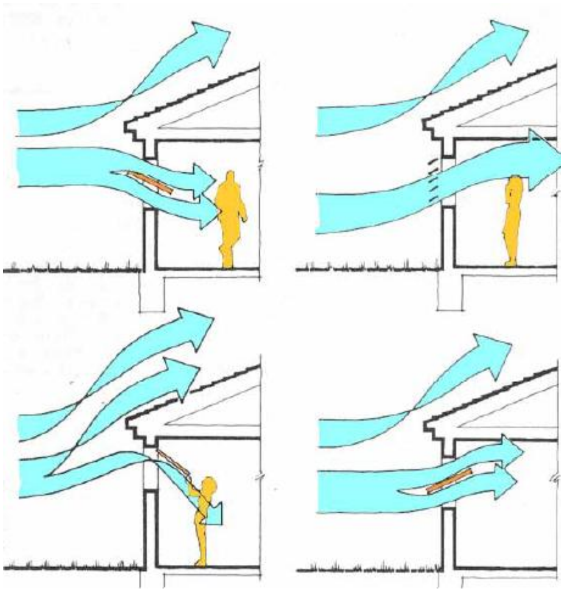


Figure 4.11 Different Types of operable vents

(A) Cross ventilation:

It is the most effective form of natural ventilation. Windows or vents placed on opposite sides of the building give natural breezes a pathway through the structure *(see Figure 4.13).* (http://sustainabilityworkshop.autodesk.com, retrieved May 14, 2012)

(B) Atriums:

It provides natural ventilation to the areas that are difficult to ventilate from the perimeter, the atrium's height allows warm air to be released at a high level and outdoor air to be brought into the building at the perimeter *(see Figure 4.12).*

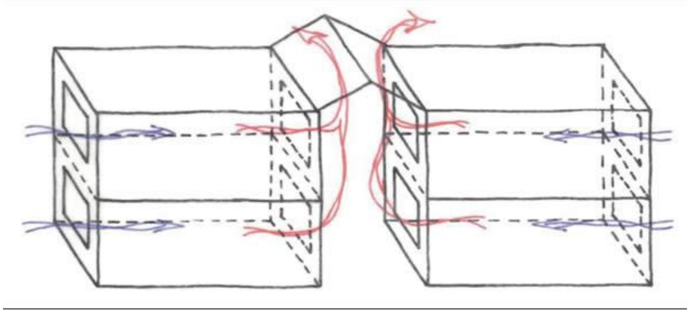


Figure 4.12 Internal Atrium

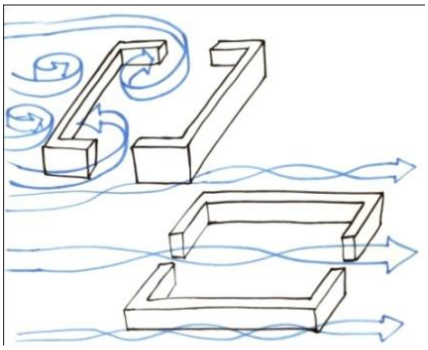


Figure 4.13 Cross Ventilation

Source: http://www.mfe.govt.nz/publications/sus-dev/passive-solar-design guidelines/html/page4.html, retrieved May 14, 2012

(C) Stack effect:

Air moves through pressure, pressure is generated by the difference of air temperature; as the warmer lighter air escapes from openings in the ceiling or roof and permits fresh air to enter lower openings to replace it *(see Figure 4.14)* (Walker, 2010).

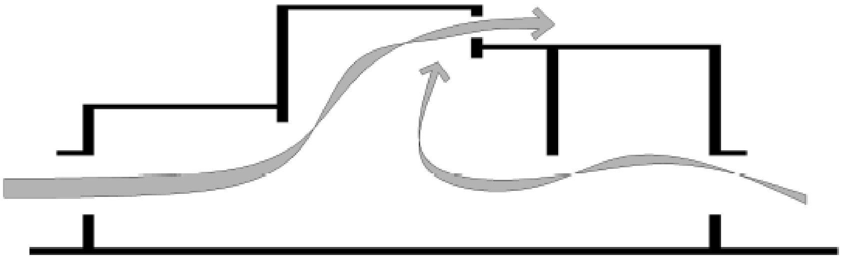


Figure 4.14 Stack Effect
Source: http://www.teriin.org/ResUpdate/reep/ch_1.pdf, retrieved July 7, 2012

4.5. Heating and Cooling (air conditioning) system:

Plants and people go well together in the vertical farm building, so the temperature and humidity profiles maintained inside the building should allow for a very pleasant work environment as well as favoring maximum crop yields (Despommier, 2010, p.p.184), heating and cooling systems, that will be used in the proposed vertical farm design, are:

4.5.1. Heat-collecting methods:

The vertical farm air temperature must be kept at plant growing and human comfort temperature. Many types of heating systems are available for use in vertical farm, such as:

(A) Boiler:

This system is used for very big greenhouses and has a centralized system of heating. The heating of the greenhouse is generally done through hot water pipes which are installed above the beds of crop and along the side wall.

Photo 4.3 A gas-fired hot-water boiler
Source:
http://aesop.rutgers.edu/~horteng/openroof5.htm, retrieved May 16, 2012

Photo 4.4 Heating pipes in greenhouse-
Source:
http://www.staklenik.rs/eng/Grejanje.html, retrieved May 16, 2012

(B) Solar Heating:

Flat plate solar heaters are used to heat the water during day time. The hot water is stored in the insulated tanks. The hot water is circulated in pipes provided along the length of the greenhouse during night. Supplementary or emergency heating systems are provided for heating the greenhouse during cloudy or rainy days (TANU, 2008).

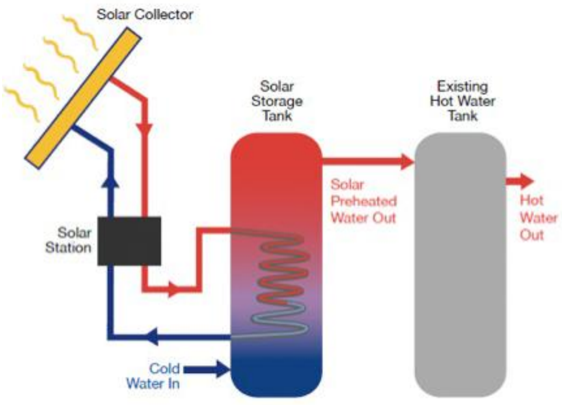


Figure 4.15 Solar hot water heating system, **Source:** http://www.earthkindsolarenergy.com/wp-content/uploads/2011/09/solar-hot-water.jpg, retrieved May 16, 2012.

4.5.2. Evaporative Cooling system (Fan and Pad system):

Evaporative cooling is a process that reduces air temperature by evaporation of water into the airstream. As water evaporates, energy is lost from the air causing its temperature to drop. The most common way of accomplishing evaporative cooling is with a fan and pad system.

Fan and pad systems consist of exhaust fans at one end of the building and a pump circulating water through and over a porous pad installed at the opposite end (Bucklin et al., 2012). The maximum center to center spacing between the two fans should be of (7.5) m. The height of the fans is to be determined based on the plant height which is proposed to be grown in the Vertical Farm building.

The cross fluted cellulose pad is preferred. These are available mostly in (100) mm thickness; one meter of pad height is given for every (20) m of pad to fan distance (TANU, 2008).

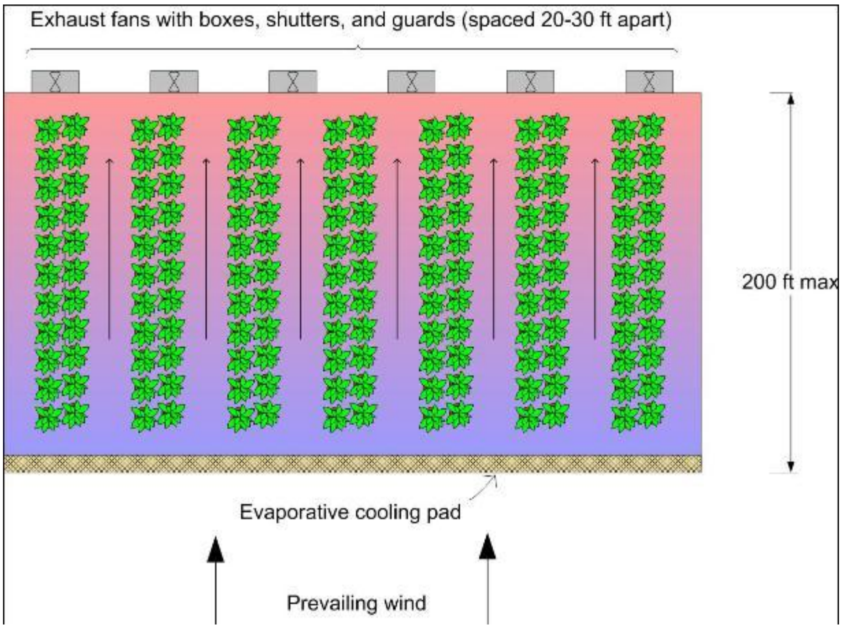


Figure 4.16 Typical Fans and Pad greenhouse
Source: (Bucklin et al., 2012).

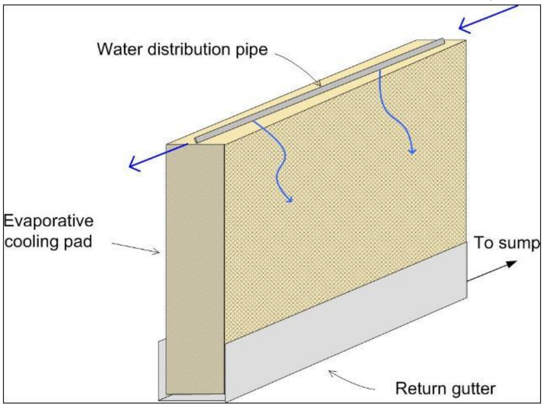


Figure 4.17 Evaporate cooling pad,
Source: (Bucklin et al., 2012).

Figure 4.18 Fan
Source: http://fileresource.sitepro.com, retrieved May 17, 2012

4.6. Waste water treatment "Living Machine":

A "living machine" is the term used to describe a particular waste water treatment that removes contaminates from water with the use of plant root systems. The waste water travels through tanks containing plant roots. Microorganisms live in the root of the plant; extract phosphorus, nitrogen, and other containments from the water (Living Machines, Inc 2003).

At the end of the series of tanks, the resulting water is pure enough to discharge directly to be recycled *(see Figure 4.19).*

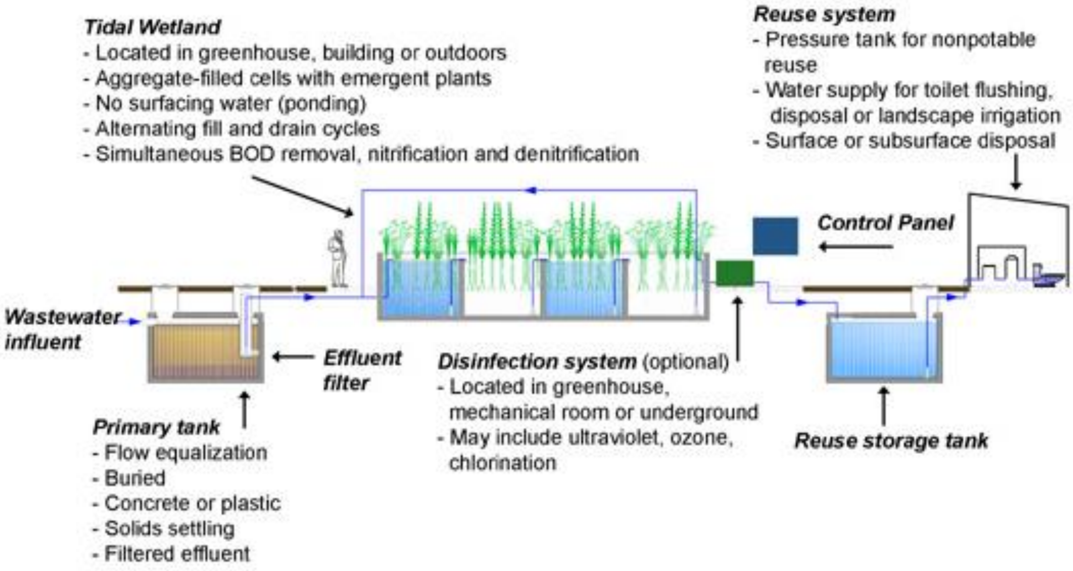


Figure 4.19 Living Machine
Source: http://www.personal.psu.edu/slj5051/living_machine2.jpg, retrieved May 18, 2012.

4.7. Waste treatment system:

The Vertical Farm will produce food, but it will also produce a significant amount of inedible plant and animal products (waste). Organic material, regardless of what form it takes is a valuable resource for use in any energy-recapture system. (Despommier, 2010, p.p.198) A common way of waste treatment is to incinerate it, and use it to produce energy, but incinerators are deeply unpopular with local communities because of the air pollution they can produce.

(A) Plasma Arc Recycling:

A new type of waste treatment called **plasma arc recycling** (sometimes referred to as "plasma recycling," "plasma gasification," "gas plasma waste treatment," "plasma waste recycling," and various other permutations of the words plasma, gas, arc, waste, and recycling) aims to change all this.

It involves heating waste to super-high temperatures to produce gas that can be burned for energy and rocky solid waste that can be used for building.

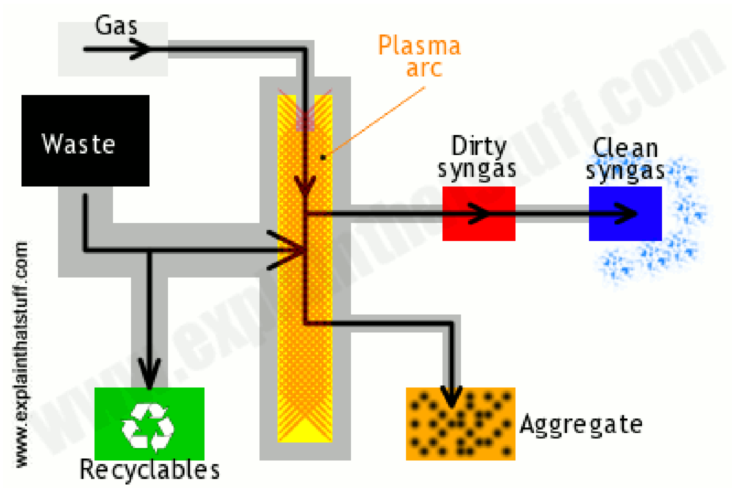


Figure 4.20 Plasma Arc Gasification process

Source: http://www.explainthatstuff.com/plasma-arc-recycling.html, retrieved May 18, 2012

(B) Anaerobic digester:

An anaerobic digester is an air tight, oxygen-free container that is fed an organic material, such as animal manure or food scraps. A biological process occurs to this mixture to produce methane gas, commonly known as biogas, along with an odor-reduced effluent. Microbes break down manure into biogas and a nutrient-rich effluent.

Figure 4.21 Anaerobic Digestion Process to produce bio-gas,

source: http://www.biogen.co.uk/uploads/Process_Diagram.JPG, retrieved may 5,2012

4.8. ETFE construction material:

If sunlight is the main source of energy to grow the crops, then the vertical farm should be made as transparent as possible. The designer\architect has many choices of transparent material to choose from. High-tech plastic is one solution that is much lighter and more durable than glass. One newer product, referred to simply as ETFE, or ethylene tetrafluoroethylene, it is a self cleaning material, due to its electrostatic charge. It is very lightweight, 2% the weight of glass of a similar section, transparent as water, allowing in all wave length of light, and has a high tensile strength.

Creating a double or even triple skin of ETFE for the outer grazing ensures good insulation and reduces the need of air-conditioning unit or heating.

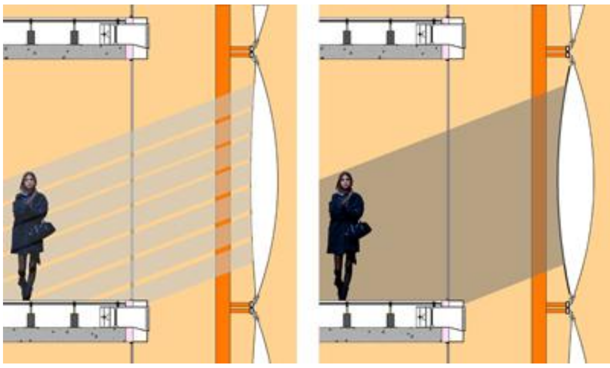


Figure 4.22 ETFE micro-domes showing the penetration of light
source:
http://hawaiidermatology.com/etfe/etfe-pillows.htm, retrieved may 10, 2012

Figure 4.23 Olympic water cube, showing the outer skin of ETFE
source:
http://www.jwz.org/blog/2004/12/water cube/, retrieved may 10, 2012

4.9. Renewable Energy: Capture passive energy for supplying a reliable source of electricity:

Fortunately, they are many choices, and generous supplies exist, these include geothermal, tidal, and wind energies (Despommier, 2010, p.p.192).

4.9.1. Solar Power (PV panels):

Solar PV system or photovoltaic solar panel systems as they are more commonly known produce electricity by collecting solar radiation from the sun's rays and convert that energy into electricity.

Solar PV system function more efficiently in direct sunlight, they are best suited for use on roof spaces that are south facing because they will be exposed to slightly more sunlight each year (http://www.enviko.com/technology/solar-pv, retrieved June 18, 2012).

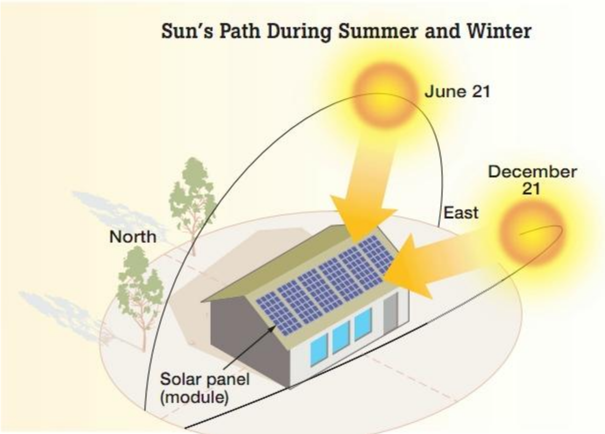


Figure 4.24 Solar Panel Module
source: http://solartribune.com/solar-panel-placement/, retrieved June 14, 2012

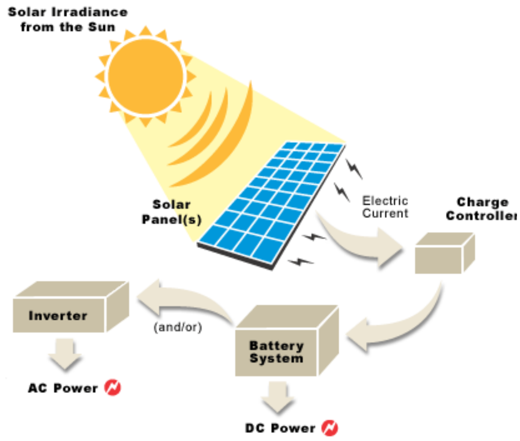


Figure 4.25 Solar Energy System,
source: http://www.jolcdi.com/wp-content/uploads/solar-pv.jpg, retrieved June 14, 2012

4.9.2. Wind turbines:

A wind turbine is a rotating machine that converts the kinetic energy of wind into electric energy (Green Paper, 2009).

For a modern wind turbine, the minimum (cut-in) wind speed required for a turbine to start generating electricity is generally between (3 and 5) m/s and depends on the size of the turbine (Abu Hamed T. et al., 2011).

Wind turbines can be separated into two categories based on the axis around which the turbine rotates: horizontal wind turbine, vertical wind turbine.

1. Horizontal axis wind turbines:

In this type of design the axis of rotation is parallel to wind direction. Horizontal axis machines can catch the wind in upwind fashion and in this case it needs a rudder to direct them toward the prevailing wind direction. If they catch the wind in a downwind fashion, they become self orienting (Ragheb, 2012)

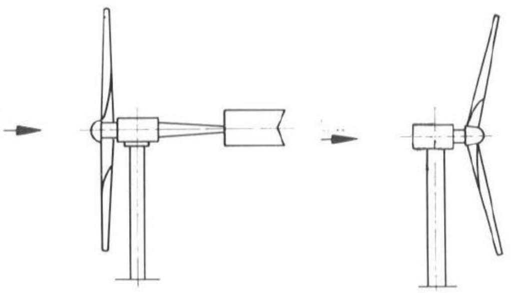


Figure 4.26 upwind and downwind design
source: http://ec.europa.eu/, retrieved June 14, 2012

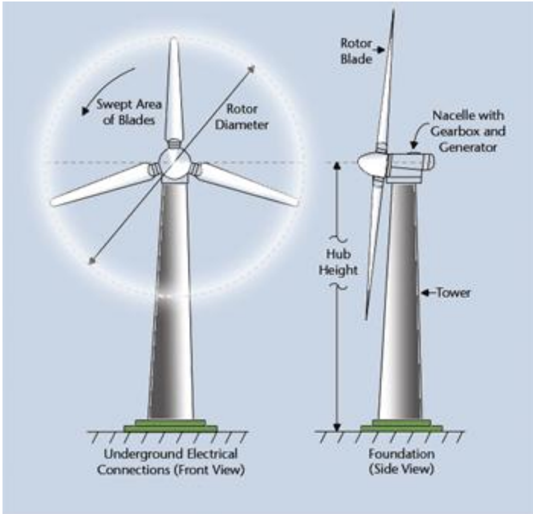


Figure 4.27 rotor and blades of horizontal wind turbine

2. Vertical wind turbines:

Vertical axis wind machines offer the advantage of being capable of catching the wind from all directions without the need to orient the blades in the wind direction, it operates almost tension, and it becomes relatively light and inexpensive to construct.

(A) quite revolution, 6 KW (B) Darrieus,3.5 KW (C) wind spire, 1.2 KW

Photo 4.5 vertical wind turbines,**source:** (Ragheb, 2012).

4.10. Hydroponic systems:

Hydroponics comes from a Latin word: hydro meaning water and ponos meaning labor which literally means "working water". Hydroponics is a method of growing plants using mineral nutrient solutions without soil (Wikipedia, February, 2012).

Today, hydroponics is an established branch of science, there has been rapid progress and results from many countries proving that it is very practical over traditional methods of horticulture.

Advantages of Hydroponic systems:

Possibly the greatest advantage to hydroponics is the increased yield of crops. Other advantages are more efficient use of water, less labor and cost involved, and certain seasonal plants can be raised during any season (Gehring, 2011, p.p.287).

Many different growing modalities of hydroponic systems arise to meet the challenge of maximizing the yield for all the crops inside *(see photo 4.6, 4.7).*

Photo 4.6 Omega Garden Carousel
Source: http://www.treehugger.com, retrieved June 2, 2012

Photo 4.7 Vertical Farming Hydroponic System
Source: http://hydroponicsnoob.com, retrieved June 3, 2012

Other types of hydroponic systems are illustrated in *Appendix 3.*

4.11. Employ good barrier design for plant protection:

Food security and safety have to be dealt with as two sides of the same coin and are the primary concerns of the vertical farm management. There are some consideration should be taken outside and inside the vertical farm building.

4.11.1. Pre-entering the vertical farm:

The seed must first be surface decontaminated, then sent to the diagnostic laboratory for testing the presence of microbial pathogens. Once certified disease-free, the seeds will be sending to the nursery for quality control testing and germination.

- Seeds will first be evaluated for their ability to germinate and grow.
- All crops will originate in the nursery as germinated seedlings, and then will be tested again for any pathogens that might have slipped through the first screen.
- The infant crop will be transferred to the vertical farm and situated into their hydroponic/aeroponic environment.
- All crops will be constantly monitored by remote sensing systems for growth and nutrient condition.

The nursery and vertical farm will be connected by a maximum security pressurized lock system (Despommier, 2010, p.p.207).

4.11.2. Inside the vertical farm:

Inside the building, things will be quite different and much more controllable.

- Designing double-lock-entry doorways will allow for an additional level of protection against insects and microbes.

- Requiring all personal to change into sterilized, disposable safety uniforms, shoe, and hair coverings, and to shower before changing clothes, will minimize the risk of crop loss. Because the vertical farm will not need fertilizers, the risk from contaminating plants with human pathogens will be all but eliminated.
- This must be coupled with an initial routine series of laboratory tests for all vertical farm workers to detect carriers of salmonella…. (Despommier, 2010, p.p.200).

Finally, this chapter illustrates the different device and technologies will be involved in the proposed Vertical Farm design, can be summed up:

- ETFE.
- Light shelf
- Parabolic mirrors
- Light tube.
- Fiber optics.
- LED\OLED.
- Solar panels.
- Wind turbines
- Cross ventilation.
- Anaerobic digester
- Living machine.
- Solar panel heating system.
- Hydroponic system.

The following chapter will discuss the main steps to locate and design the proposed model of vertical farm design. In step three will illustrate the integration of these sustainable technologies in vertical farm building design.

CHAPTER FIVE

A PROPOSED DESIGN OF VERTICAL FARM BUILDING

To plan and design a vertical farm, there are three main topics to be addressed, which can be assumed in **Three Main Steps**:

- Potential locations of the proposed Vertical Farm building.
- Crops Selection and Plant Design Requirement.
- Architectural Design process of the proposed Vertical Farm building.

5.1. STEP 1: Potential locations of the proposed Vertical Farm building

In this section, the research will identify the main criteria to consider a site location of vertical farm building, and the map of potential locations in Palestine.

5.1.1. Main Criteria of site Locations:

When considering a site location, the designer should try to meet as many of the following requirements as possible, in order to maximize building efficiency and success.

- A region which has a maximum amount of sunlight.
- Full east, south, and west exposure to sunlight.
- Flat area or one that can be easily leveled to have maximum wind power.
- Good quality water capable of supplying at least one-half gallon of water per plant per day.
- Good internal drainage system.
- Close to urban centers which have a good labor supply.
- Close to universities and educational institutions for easy access to experts.

- Access to main roads and access points outside the country such as airports and ports.
- Avoiding areas having excessively strong winds.

These general site characteristics are the conclusion of different site considerations as illustrated below:

5.1.1.1. Greenhouse Site Location:

Vertical farm building is an integration of different systems and techniques; it is a multi-story of greenhouse construction which is placed vertically above each other. So, what are the main considerations of greenhouse planning?

First, one of the most important factors to consider in choosing greenhouse location is the availability of sunlight; it must be erected on the sunniest piece of land, away from trees or buildings casting shadows (Nicholls E., 1990, p.p. 80).

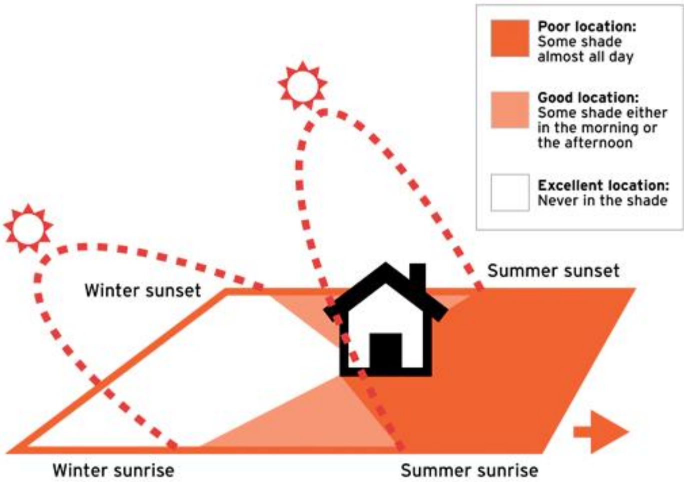


Figure 5.1 Location of greenhouse
source: http://www.solarpathfinder.com/industry-landscape, retrieved April, 16, 2012

The best location is the south or southeast side of the building, sunlight all day is best, but morning sunlight on the east side is sufficient for plant growth. The next best sites are southwest or west, where plants receive sunlight later in the day. North is the least desirable location and is good only for plants requiring little light *(see Figure 5.1).*

Good drainage is another requirement for the site. When necessary, build the greenhouse above the surrounding ground, so rainwater and irrigation water will drain

away. Also, the following criteria should be considered with regard to site selection (Zabeltitz C., 2011):

- The microclimate conditions.
- The water and electricity supply.
- Labor availability.
- The distance to the markets and transportation costs.

5.1.1.2. Hydroponic system site requirement:

Figure 5.2 Palestine Map showing the main natural water resources, and the aquifers
Source: http://www.nad-plo.org/userfiles/file/Reports/shared-water.pdf, retrieved April, 16, 201

Vertical farming site selection also needs to take into consideration hydroponic systems as special requirements are needed.

Hydroponic system need an abundance of water, which could come from several sources, depending upon the geographic location and the ability of the urban community to access grey water for reuse (Despommier, 2010), the above *Figure 5.2* illustrates the main natural water aquifers in Palestine.

5.1.1.3. Access to main roads:

Figure 5.3 Access to main airports and ports
Source: http://www.sjpucsd.org, retrieved April 1, 2012.

Road access to main international airports and ports should be available and appropriate for the types of vehicles expected to service the facility, large trucks need better and wider roads than small cars. And these routes should be short and direct to the points of exportation. *Figure 5.3* illustrates the main roads, airports, and ports access in Palestine

5.1.1.4. Climatic consideration:

Renewable energies such solar power and wind turbines require special conditions to be more efficient. The abundant of sunshine provides high levels of solar energy power, and high wind speed increases the opportunity of using wind energy as a source of electricity.

The main two zones which have the maximum sunshine per day in summer and winter is climate zone 2 (The northern part of Jordan Valley and the Southern mountains areas) and zone 3 (Starts from Hebron Mountain in the South and ends in Jenin north of the West Bank) *(see Appendix 1*), the average sunshine hours are 8 hours\day in summer, and both of them have high wind speeds reaching to 5 km\hour and is western, northwestern and southwestern directed *(see Figure 5.4).*

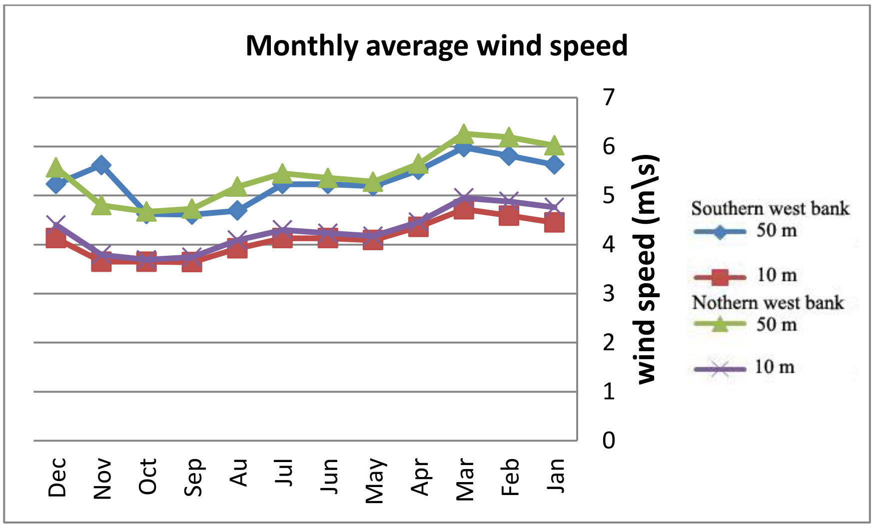


Figure 5.4 Monthly average wind speeds (m/s) for the northern and southern West Bank
source: (Abu Hamed T. et al., 2011)

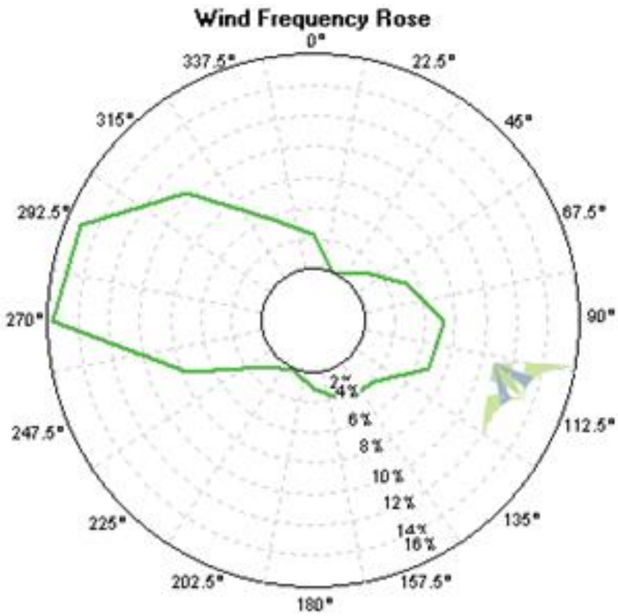


Figure 5.5 Wind rose diagram showing the wind direction in Palestine (western northern direction)
source: (Odeh, 2011)

5.1.2. Potential locations of the Vertical Farm building:

The Palestinian territories can be divided into four areas, the north, middle, and south area of west bank, and Gaza strip area.

Table 5.1 Palestinian territories main districts, area, population, population density, labor force, wage employee percentage, and wind speed

Palestinian territories	West bank			Gaza strip
Main districts	**North area**	**Middle area**	**South area**	
Area (km^2)	2206	1793	1656	365
Population (2012)	1,044,218	764,169	840,633	1,644,293
Population density(capita\km^2)	473	426	508	4,505
Labor force participation rate of persons aged 15 and over 2008**	41.9%	43.9%	46.5%	38.1%
Wage employee percentage 2008***	60.25%	72.2%	53.3%	70%
Annual Average of wind speed (m\s) at 10, 50 m	4.28,5.42*	-------	4.12,5.21*	------

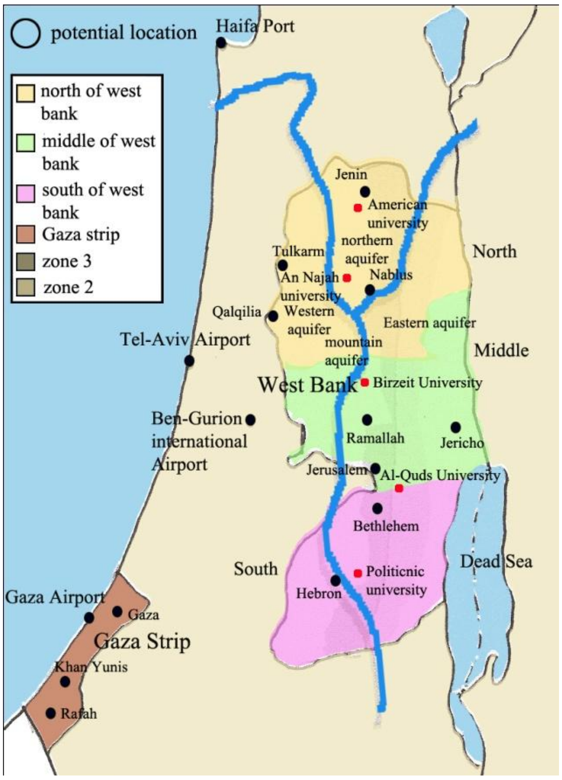
Source: (PCBS), 2010

* (Abu Hamed T. et al., 2011)

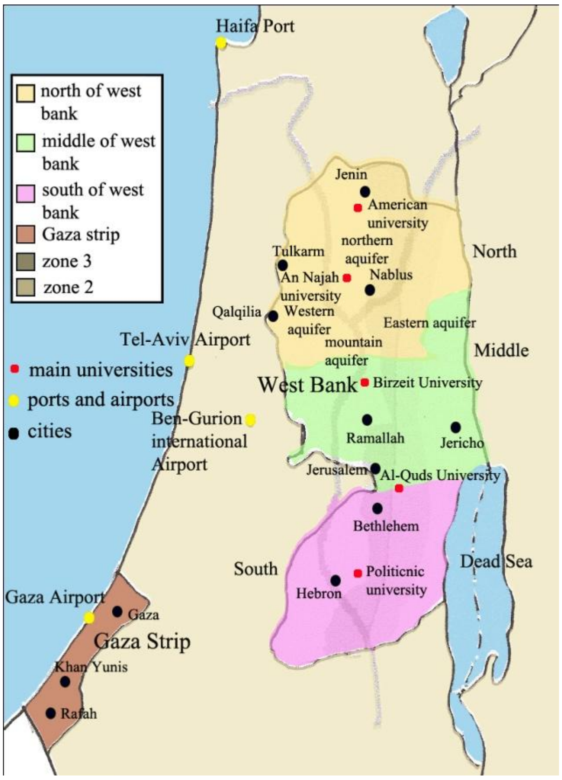
** http://www.pcbs.gov.ps/Portals/_PCBS/Documents/ca29d7c1-a87f-4df7-a4f5 163a4ae10cea.htm, retrieved April 1, 2012.

*** http://www.pcbs.gov.ps/Portals/_PCBS/Documents/011f6da5-6871-4a22-9ec3 aa9456f50434.htm, retrieved April 1, 2012.

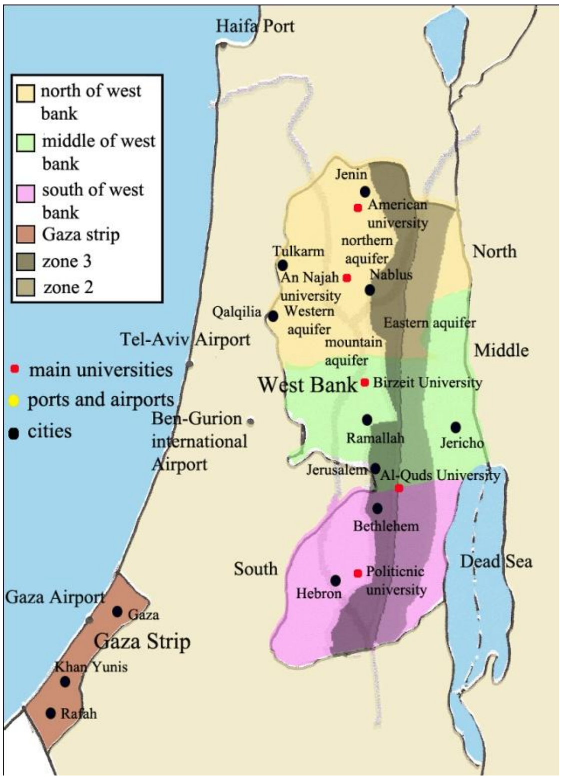
Depending on the different factors that are discussed above, the suitable climatic conditions, water resources abundant, road access to the international airports and ports, population density and economic accounts of labor force, there are many potential locations for the vertical farm building, but the best locations will be in Nablus city in the north of west bank, another good location would be in Hebron in the south of west bank. Other possible locations would be in Gaza strip which will be closed to the planned Gaza airport *(see Figure 5.7).*



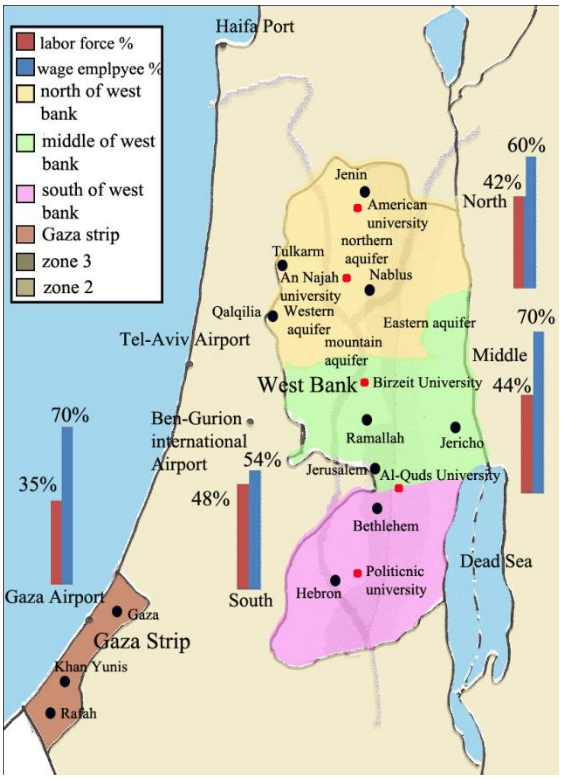
(A) A map showing natural water resources (dead sea, Mediterranean Sea), and main aquifer.



(B) A Map showing international airports and ports, access points outside country.



(C) A Map showing zone 2, and zone 3 location



(D) A Map showing labor force rate and wage employee percentage in the four districts

Figure 5.6 Factors affecting the potential location of vertical farm

Note: Zone 2, Zone 3 definitions in *Appendix 1*.

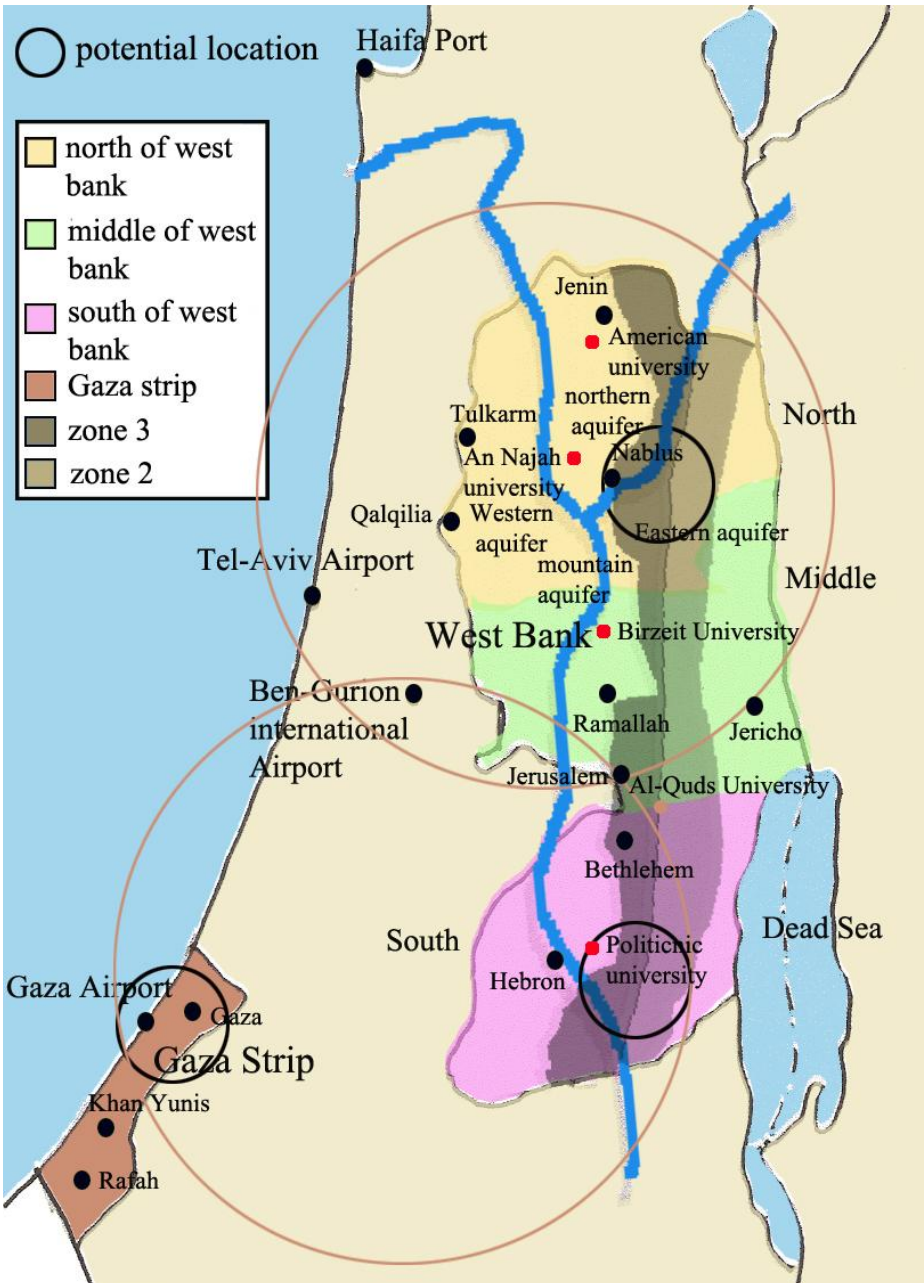


Figure 5.7 Potential Locations of Vertical Farm

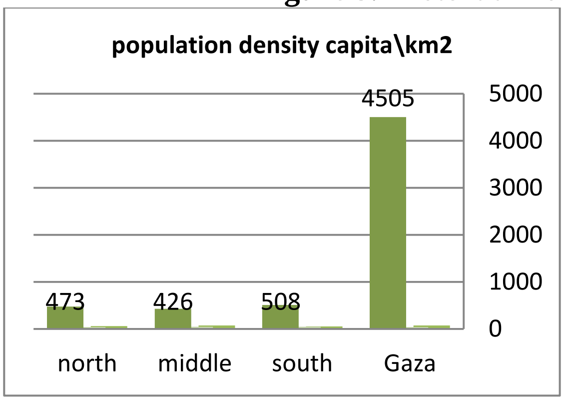


Figure 5.8 Population Density of the four main districts(north, middle, south, and Gaza strip

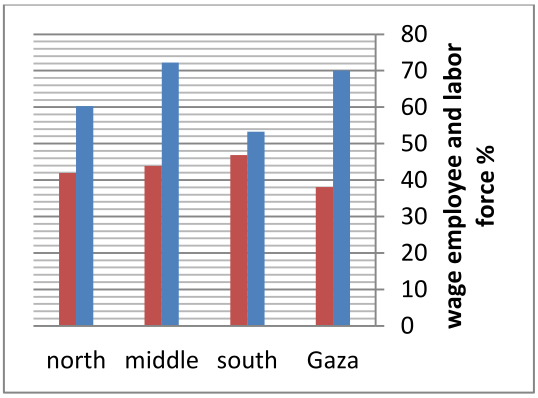


Figure 5.9 labor forces

Wage employee %
Labor forces rate %

Source: the author

5.1.3. Site Location Analysis: Nablus city

In this section, it will be an analysis of Nablus city as it is one of the best potential locations for vertical farm erection, then the possible plots area for the best location will be determined and analyzed.

5.1.3.1. Nablus City profile:

Location	Located in the northern part of west bank
Nablus area (Wikipedia, 2012)	Nablus district: (605) km^2 Nablus city: (28.57) km^2
Nablus population (2012)	(350,000) inhabitants (PCPS, 2012)
Population density	
Climatic profile	
Average temperature: 12°C in winter, 31°C in summer. **Sunshine hours:** 7.8-10.9 hours\day **Average annual rainfall:** 633 mm **Average wind speed:** 5.56 km\hour	

Figure 5.10 Nablus city location

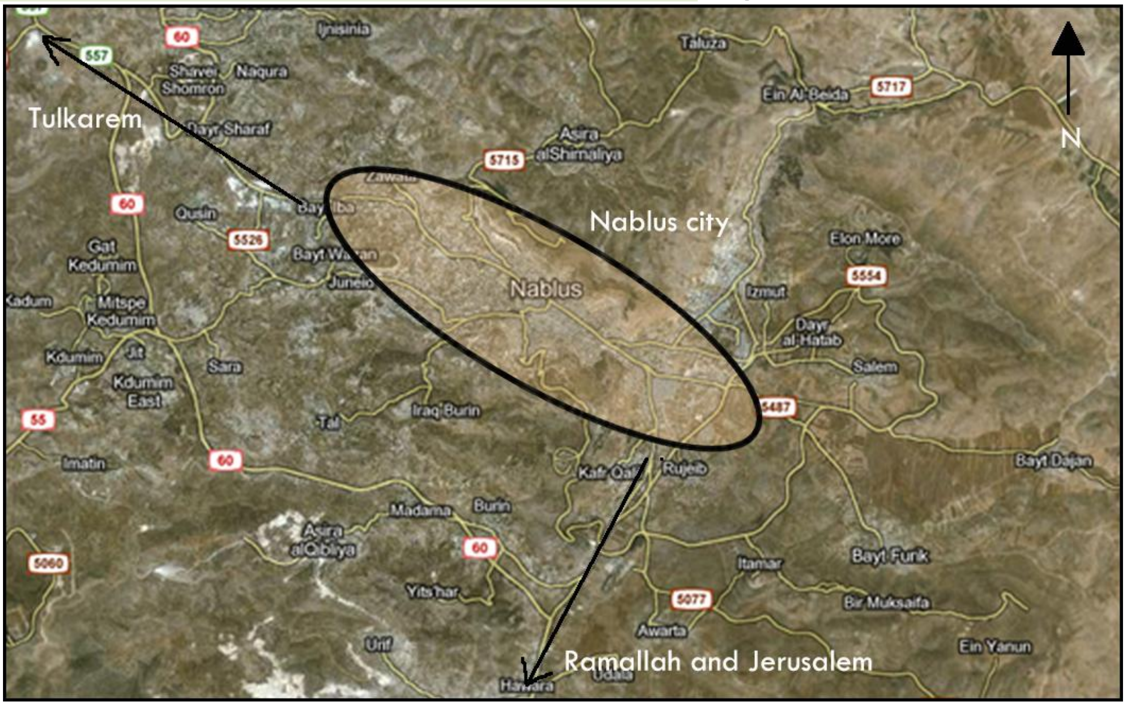


Figure 5.11 Nablus city satellite map
Source: Google Earth (2012)

The selection of Nablus city for vertical farm construction is resulted from the following reasons:

- Nablus city has the highest population among West Bank cities and considered as the major regional urban center in the northern part of the West Bank.
- The agricultural area forms only (0.4) km^2 (1%) of the total city area (Al-Hudhud, 2007).
- Agriculture plays a significant role in consuming about 3.5% of employed labor force in the city of Nablus, which means easily supply of labor force (Al-Hudhud, 2007).
- Temperature, sunshine hours, average rainfall, and wind speed, all these climatic considerations fit with most vegetables cultivation and agricultural production.

5.1.3.2. Selection of Potential plot areas:

The main road of the city, main water resources, local markets locations, and universities locations will be analyzed, and then it will be selection of the potential lots area for vertical farm erection according to site location requirements discussed before, and through checklist evaluation.

- **Nablus city main roads:**

Nablus lies at a junction between two ancient commercial roads, one linking the coast to the Jordan valley, the other linking Nablus to the north and to the south of west bank as illustrated if the following map *(see Figure 5.12)* (Al-Hudhud, 2007).

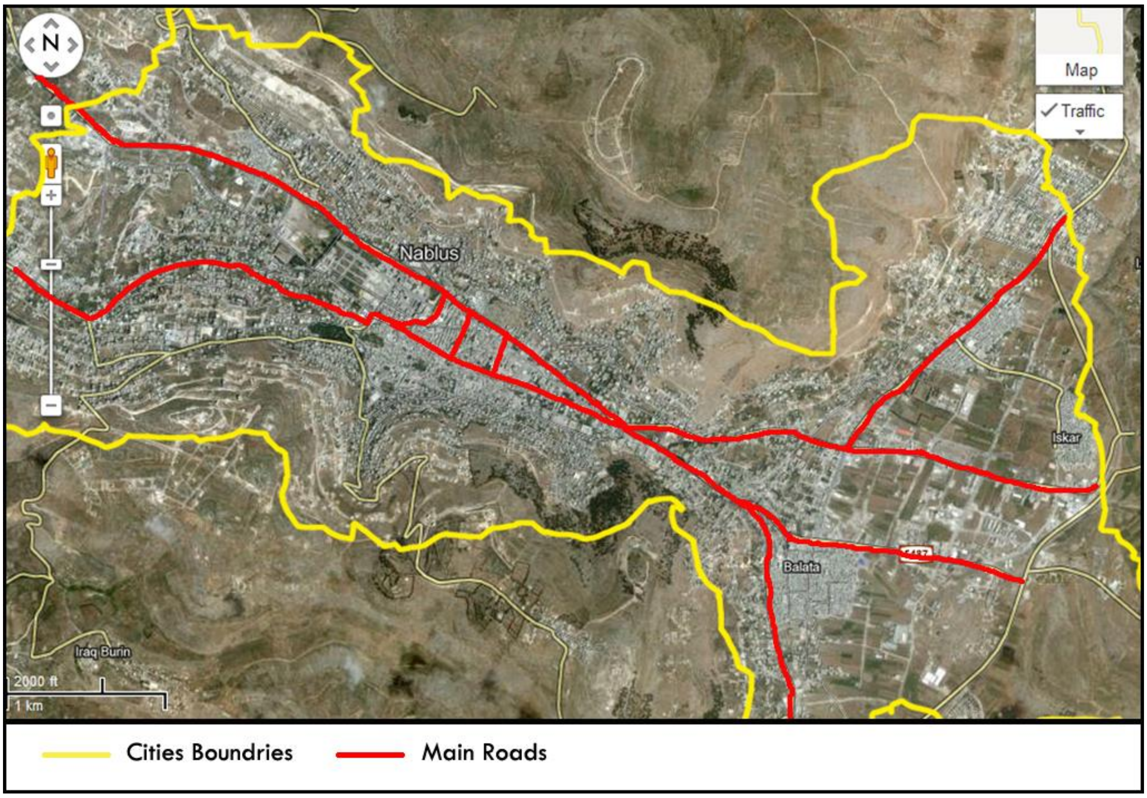


Figure 5.12 Main roads of the City of Nablus
Source: the author

- **Nablus main districts:**

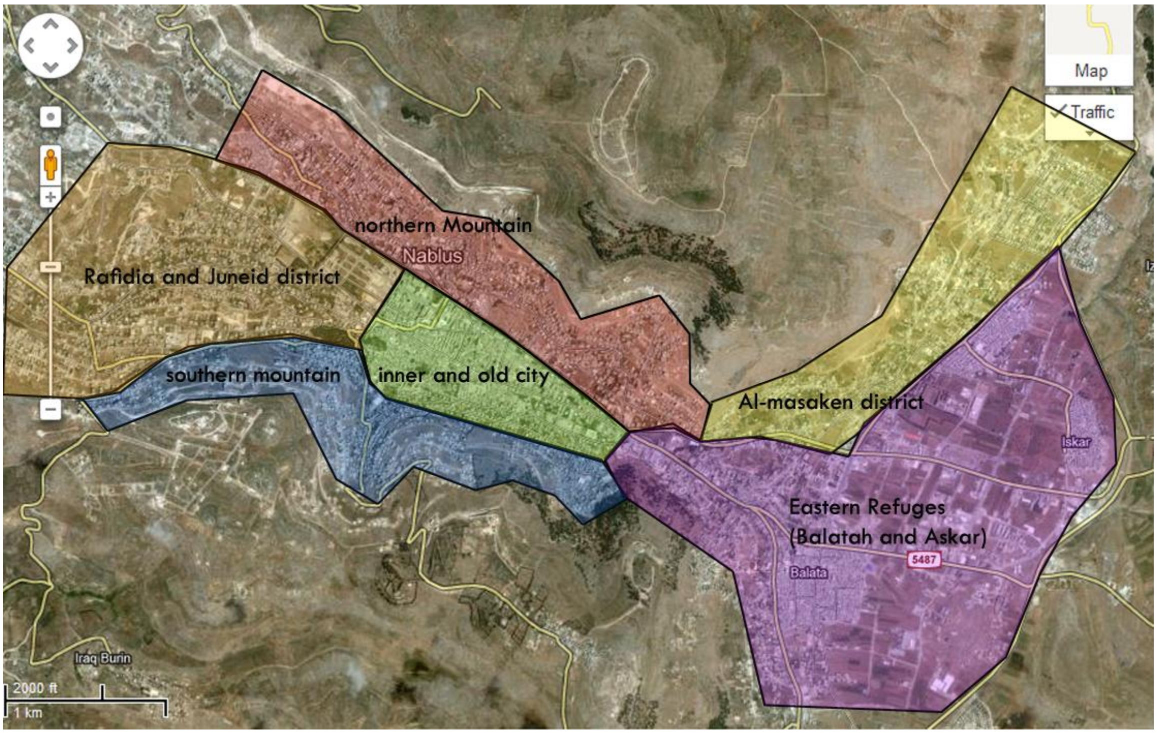


Figure 5.13 Main districts of the City of Nablus
Source: the author

- **Main universities and educational institutions:**

The following map illustrates the main universities in the City of Nablus *(see Figure 5.14).*

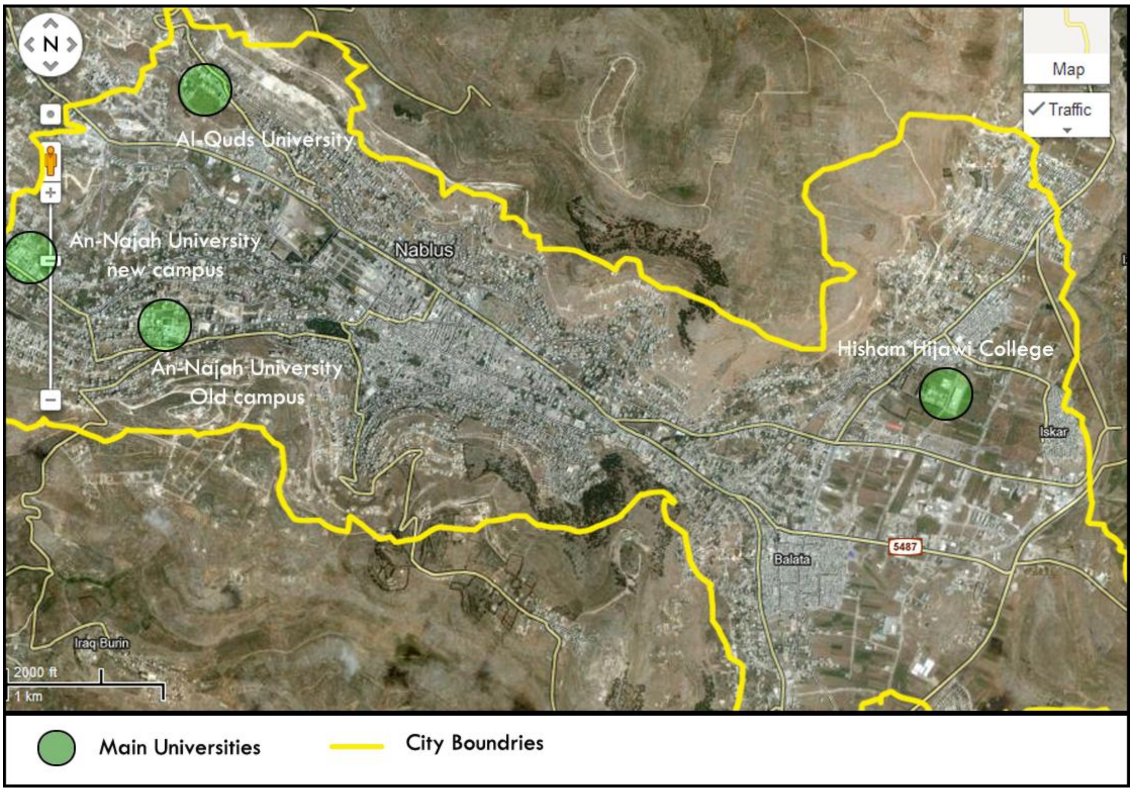


Figure 5.14 Main universities locations of the City of Nablus
Source: the author

- **Location of Main water resources (wells and springs):**

Water resources of the city come from the springs located within the city, and from the groundwater wells located outside the city boundaries *(see Figure 5.15).*

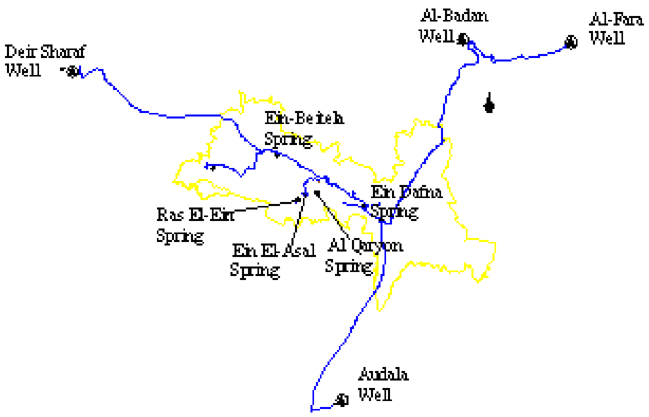


Figure 5.15 Location of water sources of the City of Nablus
Source: (Abdo, R., 2009)

Inside the City of Nablus, there are nine operating storage reservoirs that are fed from the above wells and springs *(see Table 5.2).*

Table 5.2 The storage Reservoirs of Nablus Municipality

Name	Capacity (m^3)	Condition
Ein Dafna Spring	5000	Very good
New Reservoir	3500	Very good
Northern	500	Poor
Southern	500	Moderate
Ras El-Ein Spring	500	Fair
Ein Al-Assal Spring	50	Very poor
Al-Qaryon Spring	500	Moderate
Juneid	500	Very good
Ein Biet El-Ma' Spring	250	poor

Source: (Abdo, R., 2009)

The following map *(see Figure 5.16)* illustrates the main water reservoirs functioning within city boundaries.

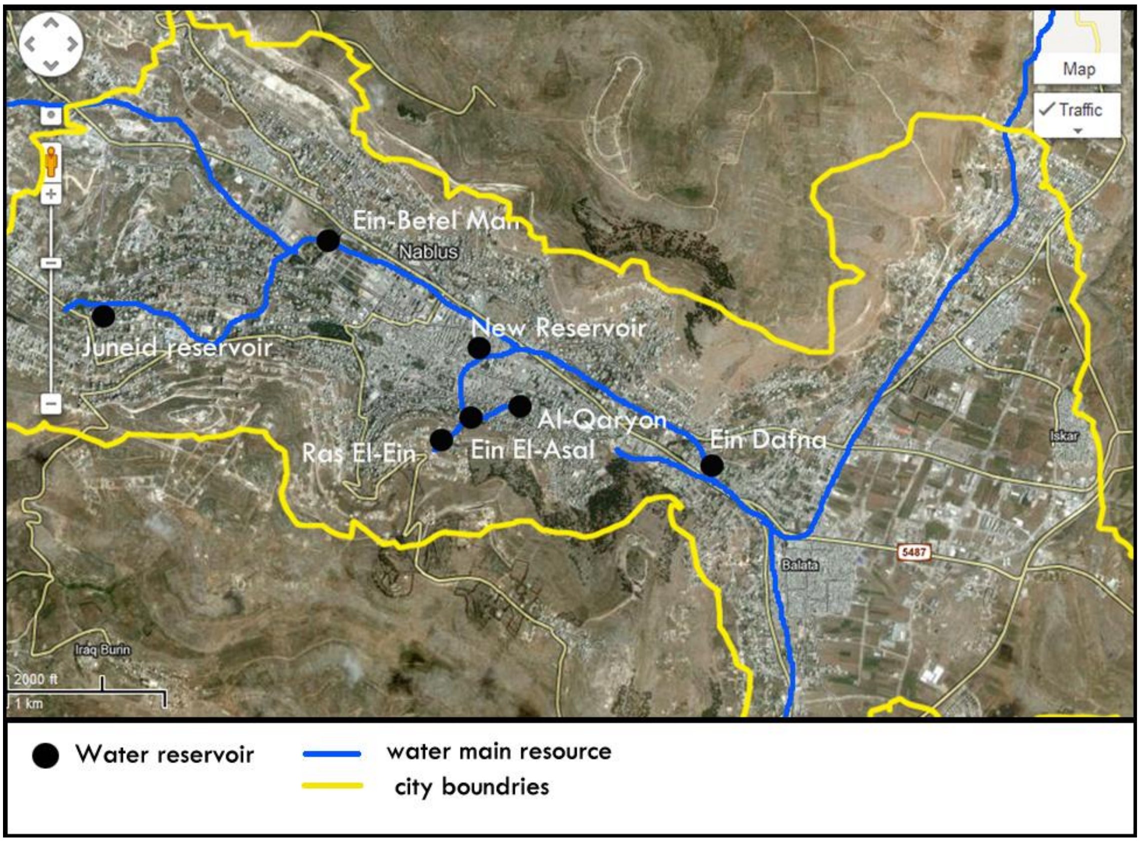


Figure 5.16 Location of water reservoirs of the City of Nablus
Source: the author

- **Local markets locations:**

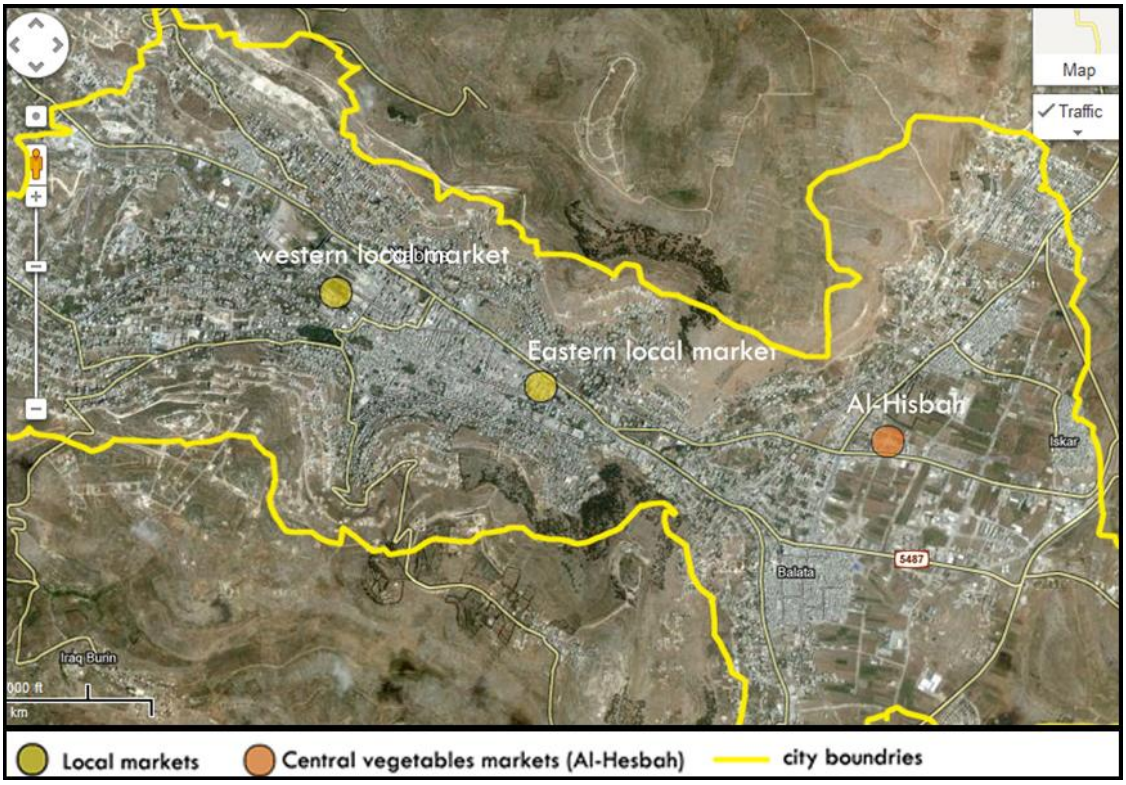


Figure 5.17 Local Markets location of the city of Nablus
Source: the author

The Central Vegetable Market of Nablus Municipality located to the east part of Nablus and regarded as vegetable and fruit basket for Nablus city and the surrounding towns and villages. There also two local markets within city center: the Western Local market and the eastern local one. The above map *(see figure 5.17)* illustrated different locations of local Vegetables markets (http://www.nablus.org, retrieved June 29, 2012).

- **Potentials plots areas:**

It can be concluded from layering all the previous maps, the possible plots area for vertical farm erection. The following map illustrates four main plots which meet the site selection requirements. In order to choose the best site, checklist evaluation is done.

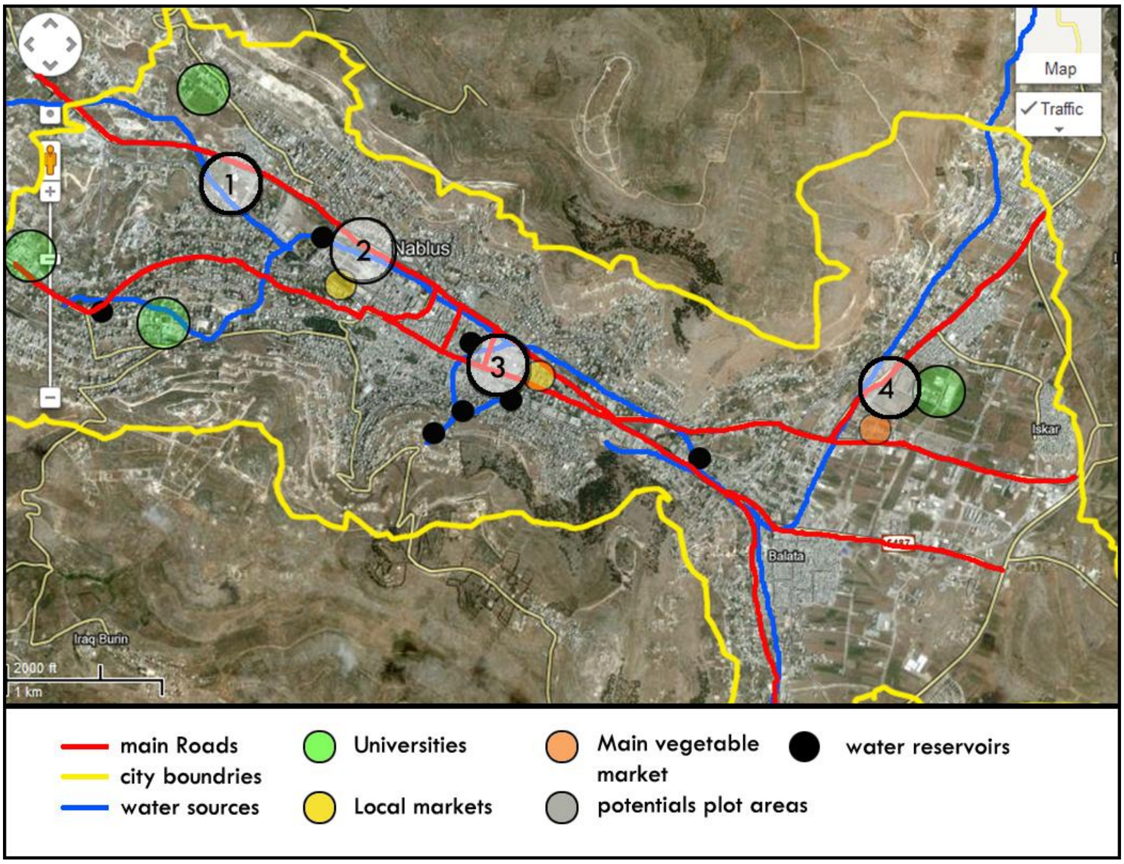


Figure 5.18 Potential plots areas of the proposed vertical farm
Source: the author

- **Analysis of the four plot areas:**

Plot 1

Location

In the western part of the City of Nablus.

Close to Ein Betel Mah reservoir (poor condition).

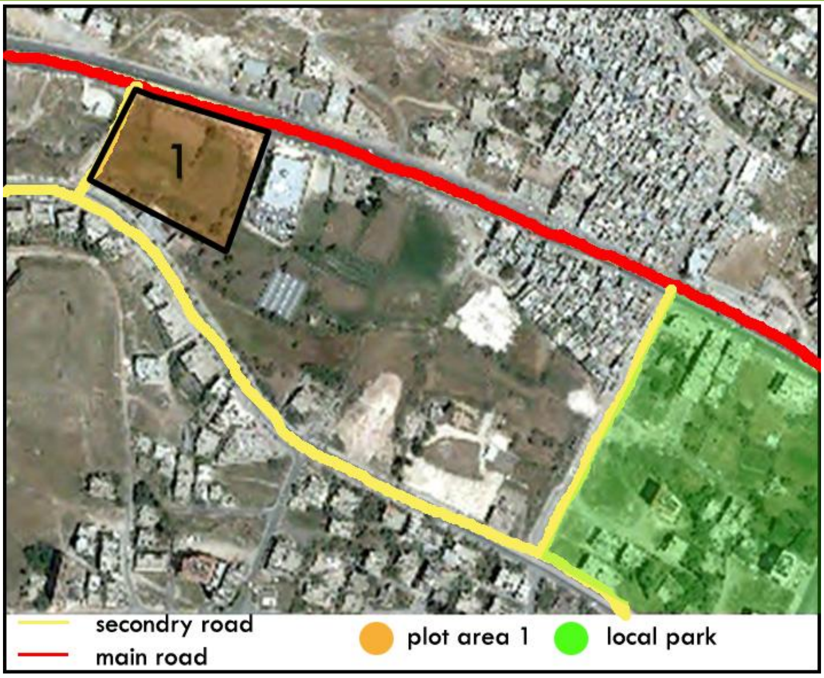


Figure 5.19 Plot area 1 satellite map
Source: Google earth

Quality item	Verification		
	Yes	No	N\A
Does the region have a maximum amount of sunlight?	✓		
Does east, south, and west exposure to full sunlight?	✓		
Is it Flat area or one that can be easily leveled to have maximum wind power?	✓		
Is there good quality water?		✓	
Is there good internal drainage system?		✓	
Is it close to urban centers that have a good labor supply?	✓		
Is it close to universities and educational institutions for easy access to experts?	✓		
Is it access to main roads and access points outside the country such as airports and ports?	✓		

It can be concluded that the plot area (1) meets most of site location requirements, but it lacks of good quality water, and internal drainage system.

Plot 2

Location

In the western part of Nablus old city.

Close to New Reservoir (very good condition)

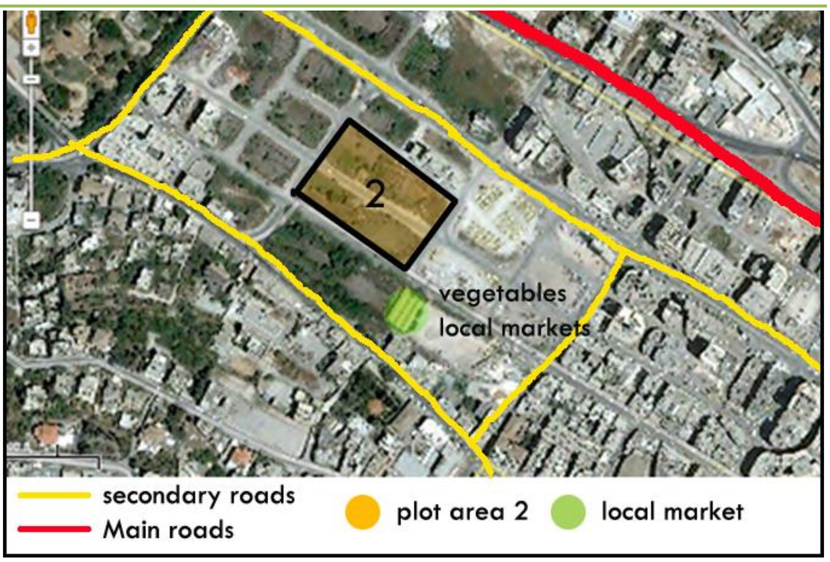


Figure 5.20 Plot area 2 satellite map
Source: Google earth

Quality item	Verification		
	Yes	No	N\A
Does the region have a maximum amount of sunlight?		✓	
Does east, south, and west exposure to full sunlight?		✓	
Is it Flat area or one that can be easily leveled to have maximum wind power?	✓		
Is there good quality water?	✓		
Is there good internal drainage system?	✓		
Is it close to urban centers that have a good labor supply?	✓		
Is it close to universities and educational institutions for easy access to experts?	✓		
Is it access to main roads and access points outside the country such as airports and ports?	✓		

It can be concluded that the plot area (2) meets most of site location requirements, except it is surrounded with high building which prevents full exposure to sunlight.

Plot 3

Location
In the middle of inner city.

Close to New Reservoir (very good condition), Ras El-Ein Spring (Fair), Ein Al-Assal Spring (very poor), and Al-Qaryon Spring (moderate).

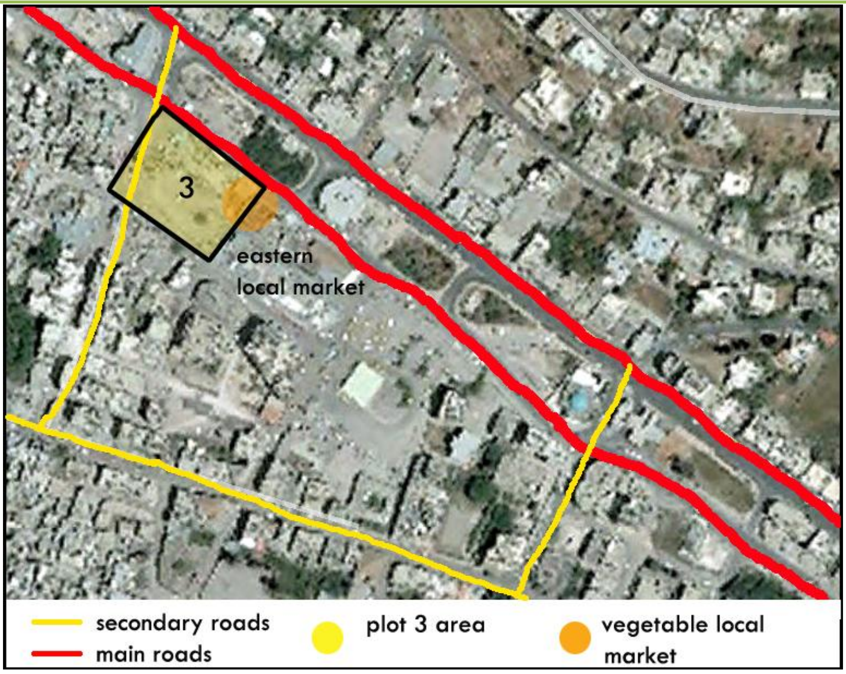


Figure 5.21 Plot area 3 satellite map
Source: Google earth

Quality item	**Verification**		
	Yes	**No**	**N\A**
Does the region have a maximum amount of sunlight?		✓	
Does east, south, and west exposure to full sunlight?		✓	
Is it Flat area or one that can be easily leveled to have maximum wind power?	✓		
Is there good quality water?	✓		
Is there good internal drainage system?	✓		
Is it close to urban centers that have a good labor supply?	✓		
Is it close to universities and educational institutions for easy access to experts?		✓	
Is it access to main roads and access points outside the country such as airports and ports?	✓		

It can be concluded that the plot area (3) meets most of site location requirements, except it is surrounded with high building which prevents full exposure to sunlight, and it is far from local universities in the city.

Plot 4

Location
In the eastern of inner city.

Close to Ein- Dafna Reservoir (very good condition).

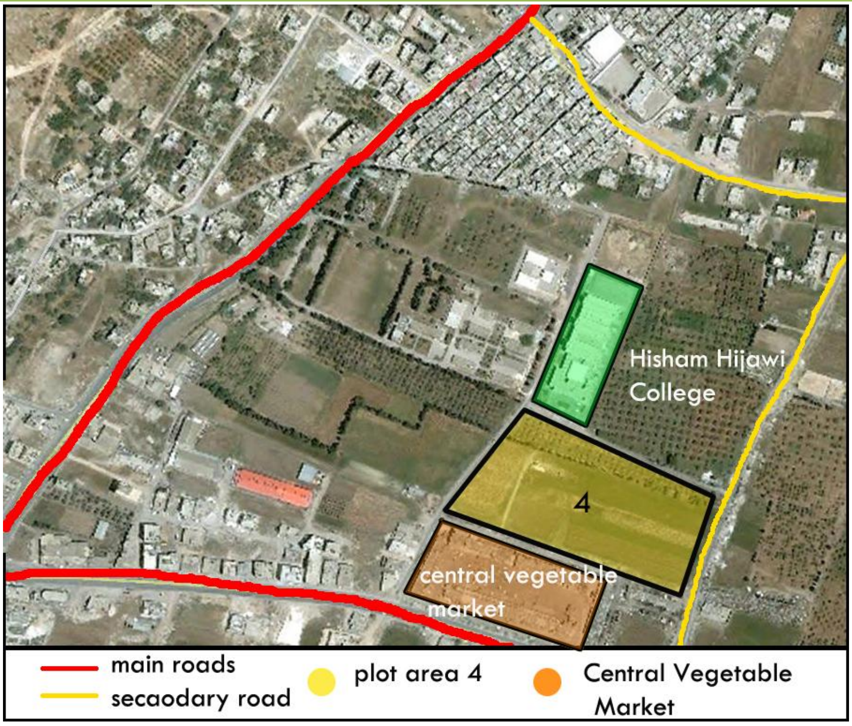


Figure 5.22 Plot area 4 satellite map
Source: Google earth

Quality item	**Verification**		
	Yes	**No**	**N\A**
Does the region have a maximum amount of sunlight?	✓		
Does east, south, and west exposure to full sunlight?	✓		
Is it Flat area or one that can be easily leveled to have maximum wind power?	✓		
Is there good quality water?	✓		
Is there good internal drainage system?	✓		
Is it close to urban centers that have a good labor supply?	✓		
Is it close to universities and educational institutions for easy access to experts?	✓		
Is it access to main roads and access points outside the country such as airports and ports?	✓		

It can be concluded that the plot area (4) meets all site location requirements, so this site is the best potential location for vertical farm erection. The following *figure (5.23)* will show the site within the surrounding context.

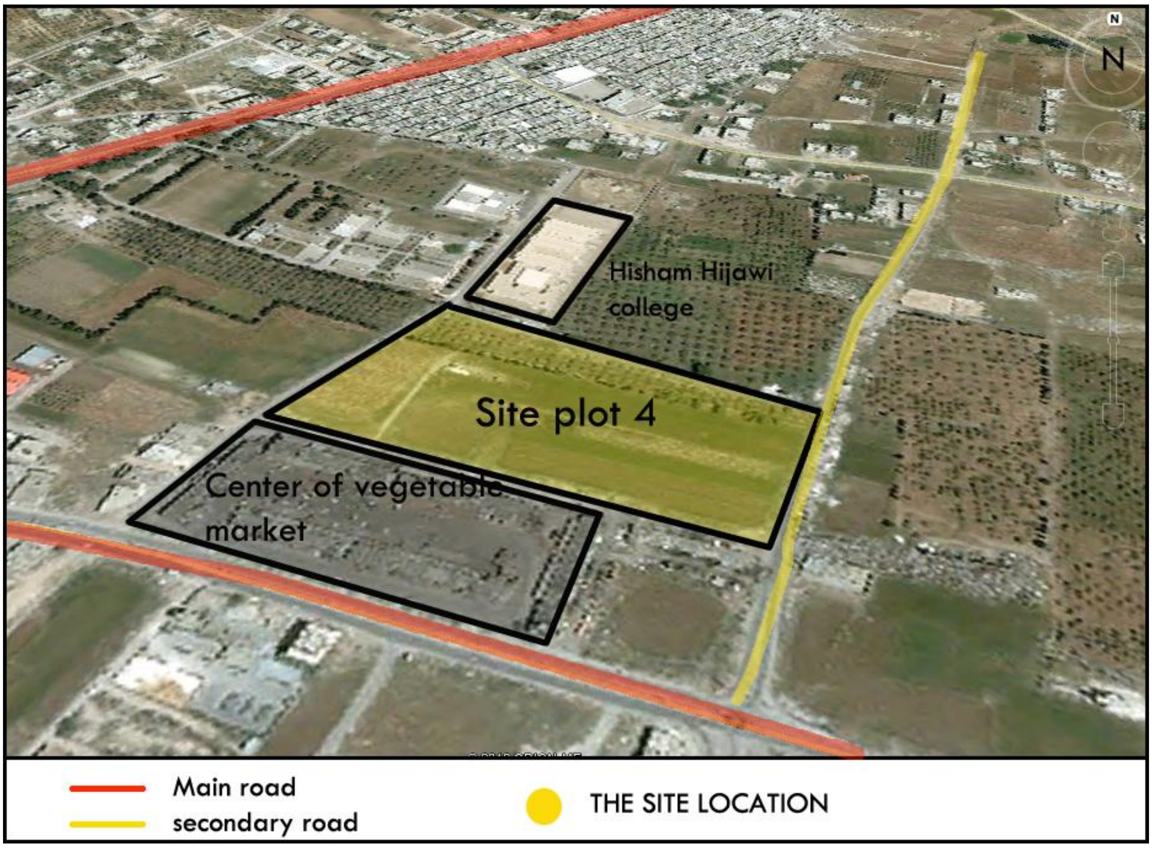


Figure 5.23 Plot area 4 Aerial view
Source: Google earth

It can be concluded from the previous analysis of vertical farm potential location, the importance of choosing the best location that meets all site requirements, saving cost and energy consumption, and making the vertical farm project more feasible economically and environmentally.

The following step is to select the main crops will be cultivated in vertical farm building, and the plant growth requirements that should be considered in building design.

5.2. STEP 2: Crops Selection and Plant design requirement

The second important step before starting the process design of Vertical Farm is to select the main crops that will be cultivated in the proposed Vertical Farm building. This section will discuss the main criteria of crop selection, and what are the environmental requirements of each selected plant, and what is the optimal method to harvest, package and store the crop.

5.2.1. Criteria of Crop Selection:

The question often arises as to which crops can be grown indoors. The answer is a surprising: "anything you want". As for the edible plants, one needs to consider several things before choosing which ones to grow.

Usually in large commercial projects, cash crops will be suitable. **Cash crops** are plants grown and sold for cash either in the domestic market or exported abroad, and may be a food such as fruits, vegetables, or non-food crop such as cut flowers.

In order to select the most suitable crops to be harvested in Vertical farm building, three main points should be considered:

(A) First, Crops can be grown hydroponically:

The types of food crops feasible for hydroponics may be severely limited by its economic potential. The viability of expensive systems climate control, rolling tables etc. should be considered during the planning stages of any project (Venter G., 2010, p.p. 112).

The most popular hydroponic vegetable crops are tomatoes, with cucumbers and bell peppers in second and third places respectively. However, leafy crops like fancy lettuce, celery, watercress, herbs, as well as strawberries, melon, watermelon, beans, radish,

carrots, etc. flowers, foliage, aromatics and medicinal plants are grown hydroponically on an ever-increasing scale (Venter G., 2010, p.p. 113).

Agricultural cereals are very inappropriate for hydroponic production due to its slow growth rate, the time required to ripen, and its low-income potential due to international price competition (Venter G., 2010, p.p. 114).

(B) Second, Crops Consumption\Production balance:

According to some calculations, the research determines the main crops that have a shortage in its production comparing to its consumption in 2010 (it is the last updated available statistics), which are illustrated in the following *Table 5.3*.

Calculation process:

Two main values should be calculated, production and consumption value, to find the production\consumption balance of each crop, then to find the main crops have negative production\consumption value.

- **Crop production value:** it can be estimated from the crop production of 2008, by considering the same yield of the crop and multiply by production area in 2010.

Crop production value = yield of production (kg\m^2)*production area (m^2)… (1)

- **Crop Consumption value:** it can be estimated by the following equation

Consumption\month= (total population\ average household size) *average household consumption for each crop… (2)

Total population of Palestinian territories = 4,048,403 (PCBS, 2010), Average household size= 6.0 (PCBS, 2010)

Consumption\month= (674,733.8 number of household) * average household consumption for each crop

Table 5.3 Production\Consumption balance of crops

Crop name (vegetables)	المحصول	Crop production 2007\2008	Crop production 2010	Crop consumption 2010	Self sufficiency= Cons. – pro.
Cucumber	خيار	208,182	117,967.2	67,849.37	50,117.83
Marrow	كوسا	48,506	30,169.84	29,417.46	752.3766
Tomato	**طماطم**	207,559	118,284.3	133,556.7	-15,272.4
Eggplant	باذنجان	59,655	45,742.04	37,691.12	8,050.915
Maize	الذرة	12,481	7,182.01	5,140.915	2,041.094
Cauliflower	**زهرة**	24,840	16,832.27	24,749.58	-7,917.31
white cabbage	**أبيض ملفوف**	22,376	9,982.667	11,959.77	-1,977.1
snake cucumber	فقوس	3,140	1,881.776	2,195.599	-313.823
okra	بامية	2,411	1,844.432	2,936.391	-1,091.96
Jew's mallow	ملوخية	12,434	5,665.028	18,680.44	-13,015.4
broad bean	فول	3,917	2,606.042	2,293.776	312.2651
green pepper	**الفلفل اخضر**	16,802	11,111.89	13,227.15	-2,115.26
kidney bean green	**فاصولياء**	5,569	3,656.947	4,417.974	-761.028
peas	بازلاء	2,208	1,738.767	1,669.012	69.75491
chick peas	الحمص	3,265	621.202	3,079.194	-2,457.99
water melon	**البطيخ**	17,282	6,008.082	52,435.55	-46,427.5
spinach	**سبانخ**	4,297	2,253.017	7,077.684	-4,824.67
onion green	البصل الأخضر	2,805	3,691.457	865.7444	2,825.712
pumpkin	اليقطين	1,355	644.8585	865.7444	-220.88
parsley	البقدونس	1,916	976.4815	2,847.139	-1,870.66
carrot	**جزر**	3,421	2,097.848	1,4066.12	-11,968.3
cowpea	اللوبيا	797	370.5724	1,044.248	-673.67
strawberry	**الفراولة**	3,150	2,656.275	2,775.7	-119.5
muskmelon	**الشمام**	3,733	3,785.349	9,594.6	-5,809.24
radish	**فجل**	2,168	716.8332	1,990.32	-1273.5
turnip	لفت نبات	2,748	1,525.32	1,410.182	115.1
lettuce	**الخس**	1,705	550.2247	2,543.682	-1,993.5
fennel	شومر	2,565	867.9653	1,097.8	-229.8
gourd	القرع	717	562.63	714.016	-151.4
dry garlic	ثوم	1,371	126.5	1,651.16	-1,524.7
green thyme	**زعتر اخضر**	3,227	3,063.8	1,392.3	1,671.5
green sage	**ميرامية خضراء**	203	206.2	187.4	18.7
mint	**نعنع**	108	104.4	776.5	-672.08
avocado	افوكادو	344	523.3	8,943.05	-8,419.75
potato	**بطاطا**	69,180	45,127	98,230.7	-53,103.7

Note: consumption: tons

Source: the author

In the following *(Figure 5.24)*, the crops are listed in descending order from the highest shortage percentage to lowest one, these crops are:

Potatoes, water melon, tomatoes, Jew's mallow, carrot, avocado, cauliflower, muskmelon, spinach, chick peas, green pepper, lettuce, white cabbage, parsley, dry garlic, radish, okra, kidney bean green, cowpea, mint, snake cucumber, fennel, pumpkin, strawberry, and gourd.

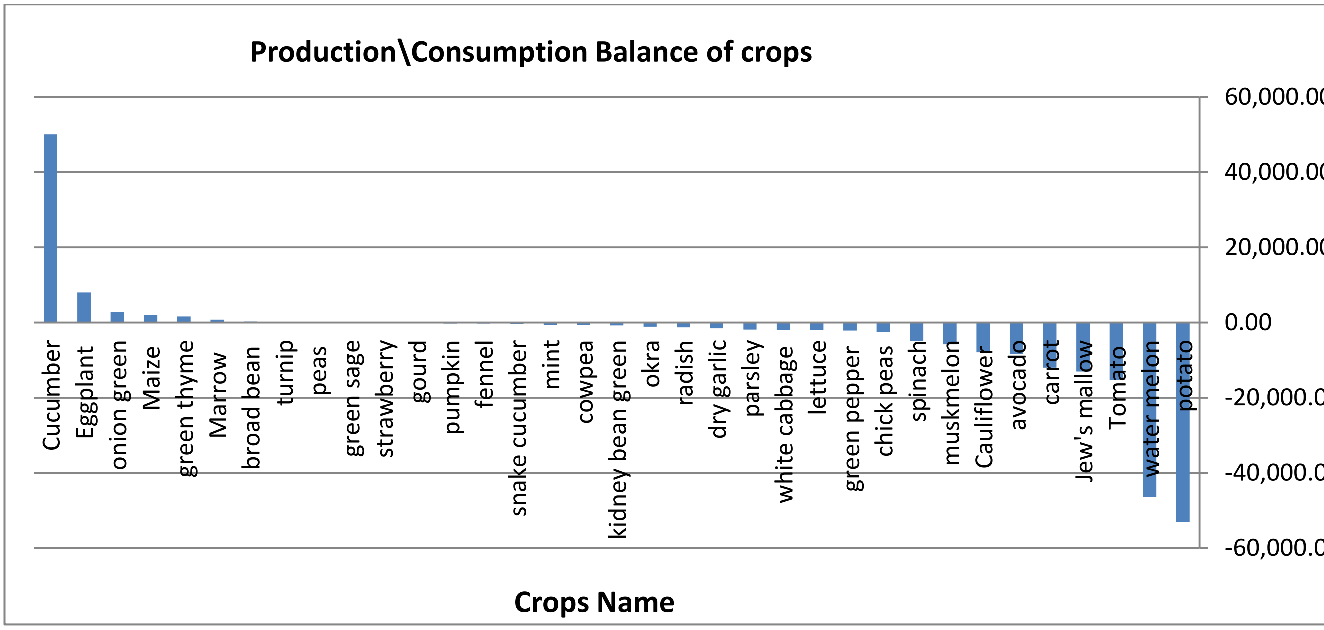


Figure 5.24 Graph shows vegetables arrangement in descending order according to consumption\production balance

Source: the author

(C) Third, Economic consideration and Profit:

The profit is what the farmer could return from selling out the crop, and that is the main driving force behind this particular Vertical Farm. So far, a few popular vegetables have been grown successfully for profit; these include tomatoes, lettuce, spinach, zucchini, green peppers, green beans, and the strawberry (Despommier, 2010, p.p. 209).

According to the analysis, the crops will be nominated to be grown in the Vertical Farm are **tomatoes, peppers, watermelon, strawberries, lettuce, spinach, chicory, and herbs (green thyme, mint, basil, and parsley),** which can be divided into three groups:

Table 5.4 The three main groups of the selected crops

Group 1 (Warm season crops)	**Group 2 (Cold season crops)**	**Group 3 (Herbs)**
Tomatoes	Lettuce	Green thyme
Peppers	Spinach	Mint
Watermelon	Chicory	Basil
Strawberries		Parsley

5.2.2. Plant Design Requirement:

(Growth environmental requirement, harvest, and post harvest process)

Designing a large, secure home for plants requires intimate knowledge of what a plant needs and how it all works together to allow the maximum growth.

In this section, the research will identify the main plant growth requirement of water, nutrients, air, and sunlight, and what are the suitable hydroponic or aeroponic systems, and the optimal method to harvest and store the crop.

5.2.2.1. Environmental Requirement of the selected crops:

The plants require water, a few elements including carbon dioxide, a source of organic nitrogen, and sunlight to grow. Also, plants require certain climate conditions for optimal growth. The relative humidity and temperature should fall within certain maximum and minimum values (Venter G., 2010, p.p. 114).

(A) Group 1: (Tomatoes, peppers, watermelon, and strawberries)

Table 5.5 Group one environmental requirements (Temperature, sunlight, air, humidity, and PH)

Crop	Optimum temperature*	Sunlight**	Air	Humidity	PH value
Tomatoes	21^o C^o to 26^o C day time 16^o C to 18^o C for night	14 hours to 18 hours	Good air circulation	65-85%	5.5-6.5
Peppers	23-26^o C during the day and 21^o C at night	18 hours\day	----	75%	5.5-6
Watermelon	Hot	High light	----	60-70%	5.8
Strawberries	21^o C for the day time, and 14^o C for night time	10 or more hours of sunlight	----	----	6

Source: * (Hydroponics, April 8, 2012), ** (Aggie Horticulture, 2005)

(B) Group 2: (lettuce, Spinach, and Chicory)

Table 5.6 Group two environmental requirements (Temperature, sunlight, humidity, and PH)

Crop	Optimum* temperature	Sunlight**	Humidity	PH value
Lettuce	17°C - 27°C, at day 2°C - 12°C At night	Six hours or so of morning sun	95%	6-7
Spinach	Cool to warm 21-26 °C	Medium light, 8 hours of light/day	90%	6-7
Chicory	15-18 °C	Medium light, 8 hours of light/day	95%	5.5

Source: * (Hydroponics, April 8, 2012)**, **** (Kline, August, 2010).

(C) Group 3: (Medicinal Herbs)

Table 5.7 Group three environmental requirements (Temperature, sunlight, air, humidity, and PH)

Crop	Optimum* temperature	Sunlight**	Humidity	PH value
Thyme	16-24 °C	High light		5.5- 6.5
Mint	16-24 °C	medium to high light		5.5- 6.5
Basil	16-24 °C	High light		5.5- 6.5
Parsley	16-24 °C	High light		5.5-7

Source: http://hydroponicshabitat.com/hydroponics-plants, retrieved April 27, 2012

5.2.2.2. Suitable Hydroponic or Aeroponic system:

The suitable hydroponic systems of each crop will be illustrated in the following *Table 5.8 (see Appendix 3).*

Table 5.8 Suitable Hydroponic systems of Group one

Group 1	Suitable Hydroponic system	
Tomatoes drip irrigation systems, ebb and flow systems, and aeroponics For larger plant systems and commercial growing, a drip irrigation system is often used Hydroponic (habitat, 2012).	 Drip irrigation of tomatoes, double rows **Source:** http://www.cropking.com, retrieved May 12, 2012	 Drip irrigation of tomatoes, single row **Source**: http://hydroponicsfordummies.homehydroponics.info, retrieved May 12, 2012
Peppers Peppers are particularly suited to drip systems, and NFT system	 NFT hydroponic system, peppers **source**: http://www.mosesong.com/?p=104, Retrieved April 15, 2012	 Drip irrigation, pepper **source:** http://www.jiffygroup.com.jpg, Retrieved April 15, 2012
Water melon drip irrigation systems	 auto pot drip irrigation hydroponic system **source:** http://gardenworld.net.au/gardenworld/hydroponics/**,** retrieved May 24, 2012	 Hanging melon **source:** http://www.hydroponicsequipment.co/2011/07/12/hydroponic-growing/**,** retrieved May 24, 2012

Strawberries Suited to growing using the nutrient film technique (NFT) (habitat, 2012).	 Hanging NFT strawberries **source:** http://www.theinnovationdiaries.com, retrieved May 26	 A frame NFT strawberries **source:** http://3.bp.blogspot.com, retrieved May 26, 2011
Group Two		
Lettuce suited to being grown in water culture, or using the nutrient film technique (NFT) (Habitat, 2012)	 A Frame NFT system	 Fully grown NFT lettuce
	Source: http://hydroponicadvisory.com.au/systems_and_growing_media.html, Retrieved May 9, 2012	
Spinach suited to being grown in drip irrigation, or using the nutrient film technique (NFT), or A frame hydroponic system (Habitat, 2012)	 Drip irrigation, hydroponic system, **source:** http://www.h.chibau.jp/sosai/e/iodine.htm, retrieved may, 5, 2012	 A frame aeroponic system **source:** http://www.sensiblebite.com/2010/11/what-on-earth-do-i-do-with-this-kale.html, retrieved May 7, 2012

Chicory NFT hydroponic system

Chicory NFT hydroponic system, **Source:** http://www.gode.fr/uk/default.asp?rub=3&srub=28, retrieved April 15, 2012

Group Three

Herbs can be grown just as well in NFT, and aeroponic towers

Herbs are grown in tall and rotating tower with holes on the side **source:** http://www.mosesong.com/?p=104, retrieved April 27, 2012

Mint grown by pot hydroponic system, **source:** http://www.hydroponicsequipment.co, retrieved April 27, 2012

5.2.2.3. Water quantity:

The quantity of water needed depend on the growing area, the crop, weather conditions, the time of the year and whether the heating or ventilating system is operating. The maximum amount of water required per (100) m^2 will vary from about (1,000) liters to (6,000) liters, for reasons mentioned earlier (H.Jensen and J.Malter, 1995, p.p. 65).

The following *(Table 5.9)* illustrates the estimated maximum daily water requirement for each system (bench, bedding, and pots).

Table 5.9 Estimated maximum daily water requirements:

Crops	Liters of water L\m^2	remarks
Bench crops	15	Based on twice daily watering (2*7.5)
Bedding plants	20	
Pot plants	20	
Roses	30	Based on 3 times daily watering (3*20)
Tomatoes	10	

Source: (H.Jensen and J.Malter, 1995, p.p. 65)

According to *Table 5.9*, daily water requirement can be estimated for each crop.

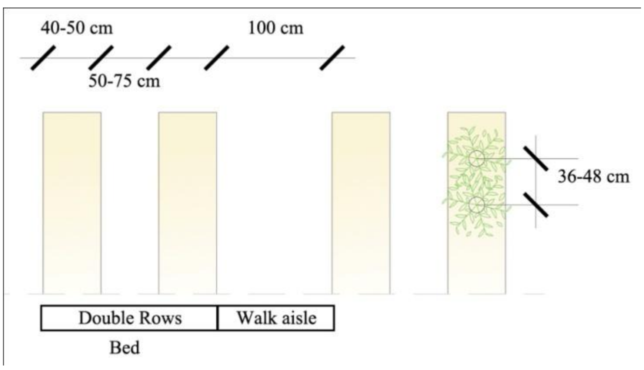
Table 5.10 Daily water requirements of the selected crop:

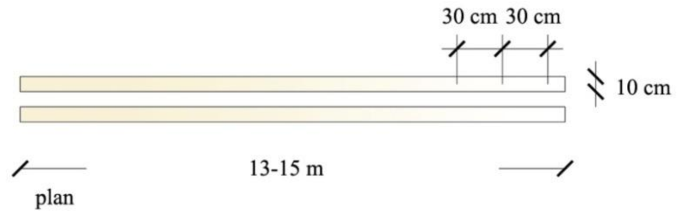
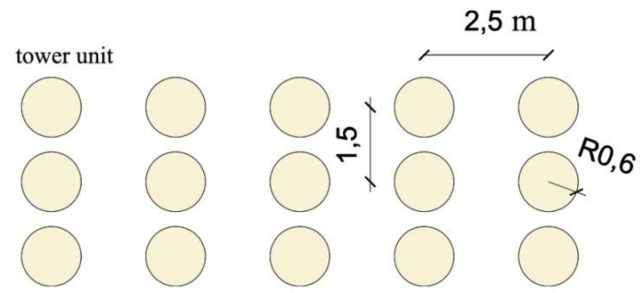
Crop name	Suitable hydroponic system	No. of crops\year	Water quantity L\ m^2
Tomato (cherry)	drip irrigation system (bed)	2	20
Peppers	Drip irrigation system (bed)	5.4	20
Watermelon	Drip irrigation system (bed)	---	20
Strawberry	NFT benches	10	15
Lettuce	NFT hydroponic system	7.6	15
Spinach	NFT hydroponic system	7.3	15
Chicory	NFT hydroponic system	7	15
Thyme	Towers aeroponic system	2	20
Mint	Towers aeroponic system	4	20
Basil	Towers aeroponic system	3	20
Parsley	Towers aeroponic system	4	20

Source: the author

5.2.2.4. Row and plant Spacing:

Table 5.11 Plant space areas, rows and work aisle width

Groups	Plant space area*	Rows and work aisles width
Group 1 (tomatoes, peppers, melon)	**.25-.37 m^2**	Plant are spaced in double rows per bed, plant rows should be 40-50 cm apart and plants 30-36 cm apart within each row. Work aisles between pairs of tomato rows are normally 1 m (M. Resh, 2004, p.p. 469).  **Figure 5.25 Rows space plan of group one plants**
Group 1 (strawberries)	**4 plant\m long**	The plant is placed in channels. The channels shouldn't be greater than 15-20 m and with a slope of 1:50. The channels should be rigid PVC in 150*75 mm for the best results (H.Jensen and J.Malter Alan, 1995).

Group 2 (lettuce, spinach, chicory)	**.0625 m^2**	The plant is grown in 2 inch PVC pipe approximately 10-12 feet long. Plants are placed in holes drilled on six inch centers (Aggie Horticulture, 2005).  **Figure 5.26 Rows space plan of group two plants**
Group 3 (herbs)	**0625 m^2**	 **Figure 5.27 Tower hydroponic system plan**

5.2.2.5. Planting and Harvesting calendar of the selected vegetables and herbs:

It is important to know the planting and harvesting dates of each crop, to organize the Vertical Farm production process, the following *(Table 5.12)* illustrates days of germination and harvest of the selected crops during the year.

Table 5.12 Planting and harvesting calendar of the selected vegetables and herbs:

crop	Days to germination	Days to harvest	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
Tomatoes	**6-8**	**60-70**										
Sweet peppers	**6-8**	**80-100**										
Watermelons	**-**	**55-85**										
Strawberries	**-**											
Lettuce	**7-14**	**65-80**										
Spinach	**7-14**	**40-50**										
Chicory	**5-7**	**60-80**										
parsley	**-**	**80-90**										
Basil	**-**	**90-120**										

Source: (Carlson, March, 2010)

5.2.2.6. Internal transport:

The filled trays or cartons have to be lifted towards a pallets or trays, and then transported to storage rooms using:

- **Transpallet:** it is used to bring the sorted and packed fruit to refrigerator.
- **Forklift truck:** in larger and more industrial settings, a forklift is likely to be used.

Photo 5.1 Transpallet Tomatoes harvesting
source: http://1.bp.blogspot.com**,** retrieved May 11, 2012

Photo 5.2 hanging cutter tomatoes in Belgium
source:http://hydroponicadvisory.com.au/systems_and_growing_media.html

Figure 5.28 Forklift truck
source: http://www.thechecker.net/images/productimages/thumbs/FL000026.png, retrieved May 11, 2012

5.2.2.7. Storage:

Commodities stored together should be capable of tolerating the same temperature, relative humidity and level of ethylene in the storage environment. In the following *table 5.13* will be the storage temperature, and relative humidity, and the length of storage for each crop.

Table 5.13 Storage condition, temperature, relative humidity, and length of storage of each plant

Vegetables and fruits	Storage condition	Temperature C^o	Relative humidity	Length of storage
lettuce	Cold and moist	0	95%	2-3weeks
Chicory	Cold and moist	0	95%	2-3 weeks
Parsley	Cold and moist	0	95%	1-2 months
spinach	Cold and moist	0	95%	10-14 days
Peppers	Cool and moist	7-10	95%	2-3 weeks
Tomatoes, green	Cool and moist	10-21	90%	1-3 weeks
Tomatoes, ripe	Cool and moist	7-10	90%	4-7 days
Watermelon	Cool and moist	5-10	80-85%	2-3 weeks

Source: http://www.gardening.cornell.edu/factsheets/vegetables/storage.pdf

Compatibility groups for storage of fruits and vegetables:

(A) Fruits and vegetables, 0 to 2°C (32 to 36°F), 95-100% relative humidity. Many products in this group are sensitive to ethylene.

(B) Fruits and vegetables, 10°C (50°F), 85-90% relative humidity. Many of these products are sensitive to ethylene. These products also are sensitive to chilling injury.

(C) Fruits and vegetables, 13 to 15°C (55 to 60°F), 85-90% relative humidity. Many of these products produce ethylene. These products also are sensitive to chilling injury.

(D) Fruits and vegetables, 18 to 21°C (65 to 70°F), 85-90% relative humidity.

Table 5.14 Selected crops groups which need the same storage condition

Group A	Group B	Group C	Group D
berries (except cranberries) lettuce spinach chicory	Peppers	tomatoes, ripe watermelons	Tomatoes, mature green

Source: (Kitinoja and Kade, 1995)

5.3. Step 3: Vertical Farm building design process:

The design concept of the proposed vertical farm is the development of a cost-effective, self- sustaining model, which have zero net emissions by using passive building design strategies…, and maximize the yield production of selected crops by using suitable hydroponic\ aeroponic systems.

The first step in building design process is to determine Vertical Farm footprint (width*length), and determine building height floors.

5.3.1. Vertical Farm Footprint:

If the primary objective is to produce a certain quantity of plant crops annually, the first step in the design process will be determine the area required for plant production. The area needed will be based on plant spacing, length of the production cycle, number of crops per year or growing season, the estimated yield per unit area and per crop cycle (Tidwell, 2012).

The proposed Vertical Farm footprint is approximately equal to the area of large size business institutions which have an average floor area of (1800) m^2. Instead of one narrow long block, it is preferred to use two square blocks, each one has a floor area of (900) m^2 (30*30). A cubic shape has the minimum effect of envelope to volume ratio on energy efficiency. Also, the taller skinnier building is better to capture maximum sunlight.

The vertical farm building is proposed to feed a population of (10,000) people. The building footprint is (30*30*2) m^2. In order to calculate the number of building floors, different calculations are done. By multiplying each crop yield production and the

(10,000) peoples consumption of this crop, the required space areas of each plant is determined.

In the following *(Table 5.15)* is a brief estimate of the total space required by each crop, and building height. Some of crops could be cultivated in stacked layers per floor; this also is considered in space calculation.

Table 5.15 Total required area of each crop to feed 10,000 people:

Vegetables	Yield* kg\m^2	Consumption * kg\person	Consumption kg\ 10,000	Space area m^2	Floors (900 m^2)
Tomatoes	68.02643	29.02	290297.6	4267.8	5.742
Peppers	59.66484	2.96	29639.8	496.8	.552
Melon	32.8	.179	1790	45.57	.05
Strawberries (2 layers)	24.97232	.62	6219.8	249.7\2	.554
Lettuce	75.19887	.56	5699.9	75.8	.084
Spinach	11.03741	1.58	15800	1432.4	1.6
Chicory**	30.2	.5	5000	165.5	.183
Herbs (tower)***					
Mint *****	3.2	.014	140	43.3	.048
Parsley***	1.5	.053	530	353	..4
Thyme****	2	.026	260	130	.2
Basil***	1.6	.02	200	125	.138
				Floors levels	**9.75**

Source:

* (Despommier, 2004 report)

** (Hill, David E., 2000)

*** http://nfrec.ifas.ufl.edu/files/pdf/publications/SVReports/crop/herbs/2002-00.pdf, Retrieved May 15, 2012

**** http://ejfa.info/index.php/ejfa/article/viewFile/5165/2636, Retrieved May 15, 2012

Ultimately, footprint of the proposed vertical farm building will be 1800 m^2 (30*30*2), and with approximately 10 floors tall.

5.3.2. Building Program\Areas:

The proposed vertical farm will include large area for growing food, offices for management, a separate control center for monitoring the overall running of the facility, a nursery for selecting and germinating seeds, a quality-control laboratory to monitor food safety, and document the nutritional status of each crop, and mega-stores to sell fresh food direct to the local market.

1. Cultivated \ crop field area:

The largest part of the program will include the main crops field area to provide enough food for (10,000) people. The (10,000) people will need approximately 12,000 m^2 of growing area. The crops being grown will be tomatoes, peppers, melon, strawberries, lettuce, spinach, chicory, and medicine plants (thyme, mint, basil, parsley) *(see table 5.16).*

Table 5.16 Required areas and floor levels of the selected crops:

Vegetables	Yield* kg\m^2	Space area (m^2)	Number of Floors (each has 600 m^2)
Tomatoes	68.02643	1800	3
Peppers	59.66484	1200	2
Melon	32.8	1200	2
Strawberries (2 layers)	24.97232	1800	3
Lettuce	75.19887	1200	2
Spinach	11.03741	1200	2
Chicory	30.2	1200	2
Mint	3.2	600	1
Parsley	1.5	600	1
Thyme	2	600	1
Basil	1.6	600	1
	Total area	**12,000**	**10**

2. Packinghouse:

There are manual and automated packing systems, both have the same process as illustrated in *(Figure 5.29).* Each floor will have a packing house unit with a maximum area of (160) m^2 (16*10) using a circular table system *(see Appendix 3).*

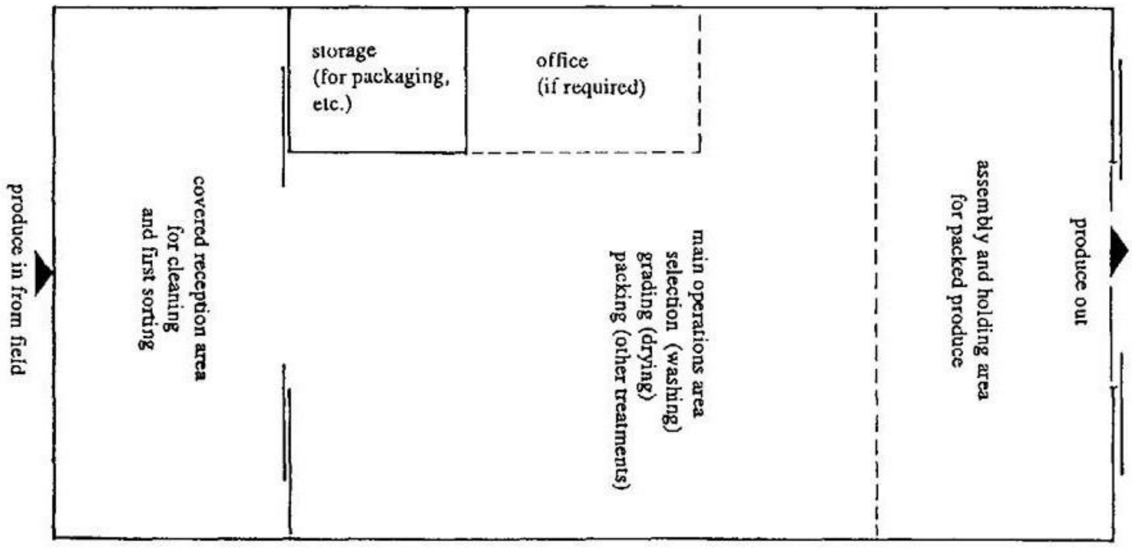


Figure 5.29 Packing House components,
source: http://www.fao.org/docrep/T0073E/T0073E0E.GIF, Retrieved April 15, 2012

3. Nursery room:

A nursery is a place where plants are propagated and grown to usable size (Wikipedia, May, 2012). The space has an entrance, employee offices, employee facilities, propagation area and production area.

The propagation area is the heart of the nursery operation and must be located in an area accessible to the production and potting areas. Propagation area size and design are determined by production type, and number of plants. The production growing areas will occupy the largest percentage of nursery land and should be adjacent to the potting area to ease the orderly movement and placement of plants in the field. The production area designs have walkways that are 2 ft (0.6 m) wide and plant beds that are 8 ft (2.4 m) wide *(see Figure 5.30, 5.31)* (Yeager, Thomas and Ingram, 2010).

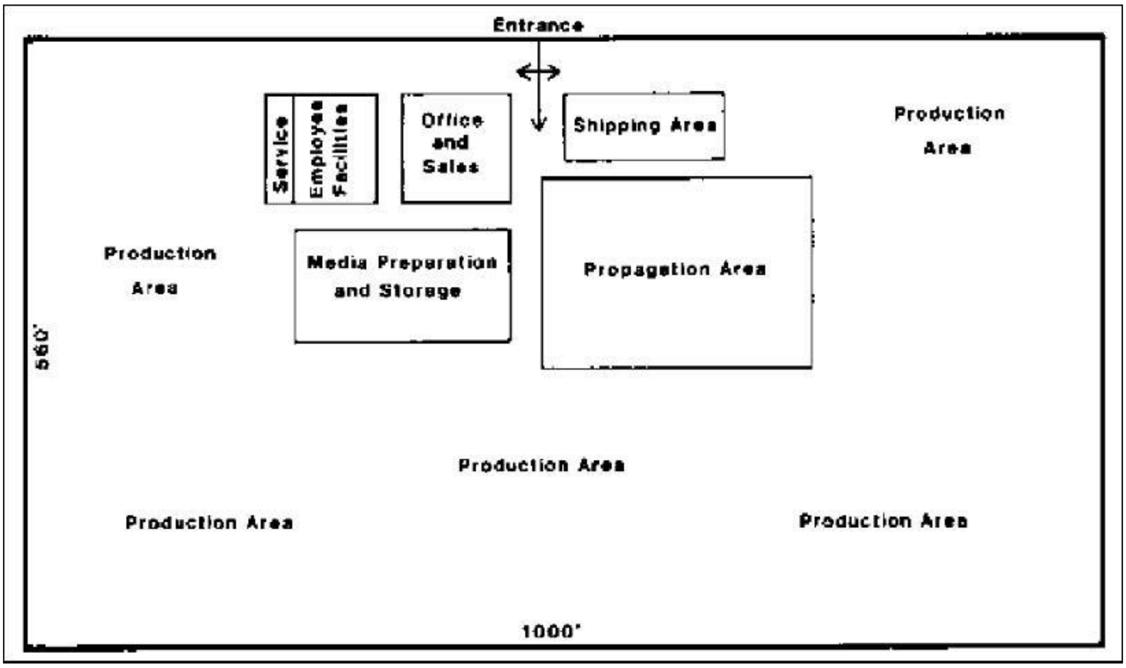


Figure 5.30 Plan of Nursery Room
source: (Yeager , Thomas and Ingram, 2010)

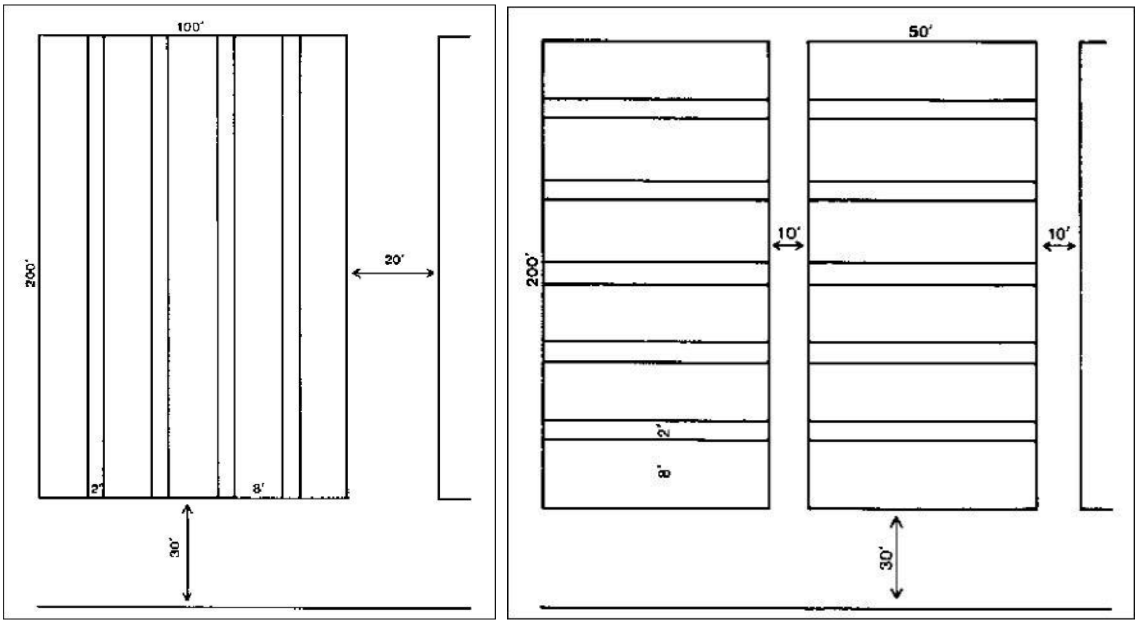


Figure 5.31 Beds rows and work aisle width
source: (Yeager et al., 2010)

Note: dimensions in the above *Figures (5.21, 5.22)* in inches, 1 inch = 0.0254 m.

The following *table (5.17)* illustrates the requiring area of seeds germination, and the total area of nursery room.

Table 5.17 Required area of nursery room, calculated by the author:

Vegetable plant	Yield kg\m^2	Plant space	Number of plants\m^2	Number of plant\600 m^2	Seed space	Require Seed area\600 m^2 (A)	Total area (number of floors*A)
Tomatoes	68.026	40*60 cm	4	2400	4*4 cm	3.84	3*3.84= 11.52
Peppers	59.664	40*60 cm	4	2400	4*4 cm	3.84	2*3.84= 7.68
Melon	32.8	40*60 cm	4	2400	4*4 cm	3.84	2*3.84= 7.68
Strawberries	24.972	4 plant\m long	Two layers 8 plant\m long	800	5*5 cm	2	2*2= 4
Lettuce	75.198	25*25 cm	16	9600	10*10 cm	96	2*96 = 192
Spinach	11.037	25*25 cm	16	9600	10*10 cm	96	2*96 = 192
Chicory	30.2	15*15 cm	44.5	3560	----	----	----
Herbs	-	25*25 cm(pot)	16	9600	10*10 cm	96	4*96=384
						Minimum Required area	**800**

Seed germination of each plant in the nursery room need a specific temperature and humidity level, for example tomatoes and peppers need 24-26 C^o both day and night (M. Resh, 2004, p.p. 466).

4. Diagnostic laboratories:

The seeds must first be sent to the diagnostic laboratory for testing the presence of microbial pathogens. Once certified disease-free, the seeds will be sent to the nursery for germination.

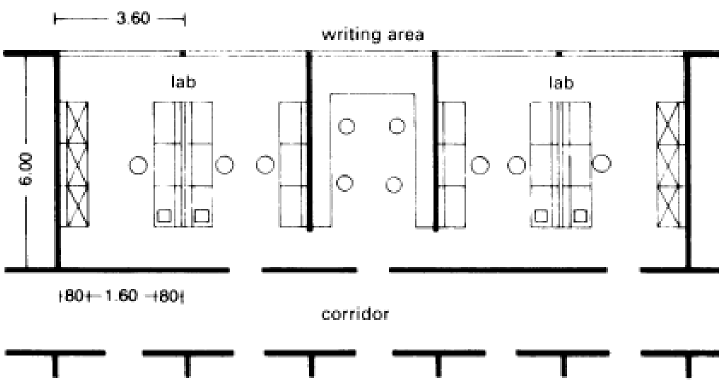


Figure 5.32 Plan of research lab
source: Neufert, p.p. 321
Note: dimension in m

5. Employee Offices:

Offices will be used by the people who are keeping the building running smoothly. They may include researchers, specialists\ technicians, and business administration dealing with the marketplace. The meeting room will help in additional support for when collaboration is needed. The following *table 5.18* illustrates the required area of employee offices.

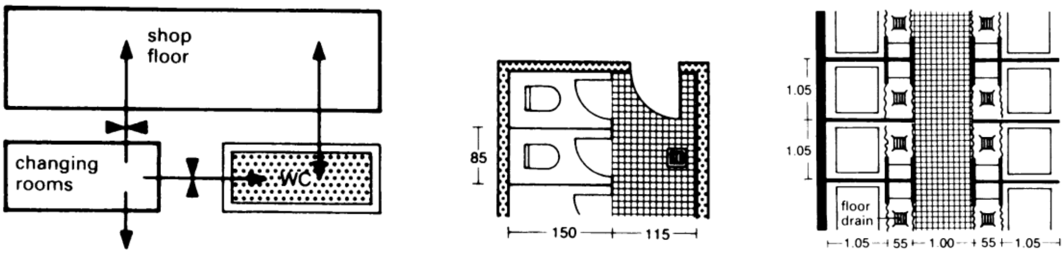
Table 5.18 Required area of employee offices (administration, experts, and farmers)

Employees	Space area (m^2)	Number of employees	Total area
Administration			
President	**28**	**1**	**28**
Assistant president	**18**	**1**	**18**
Director	**13.4**	**1**	**13.4**
Secretary	**6.7**	**1**	**6.7**
Meeting room	**40**	**1**	**40**
Departments (marketing, maintenance, coordination)			
Departmental manager	**10**	**3**	**30**
Office employees	**4.5**	**20**	**90**
Farmers	**-**	**14**	**-**
		Total area	**226 m^2**

Source: Neufert, 3rd edition

6. Employee\farmer facilities:

Pre-entering the field crop area, farmers and workers should shower and then change into sterilized, disposable safety uniforms, shoes, and hair coverings and to minimize the risk of crop loss, and eliminate the risk from contaminating plants with human pathogens. Therefore, employee facilities will include WCs, showers, personal lockers, and changing rooms.



(A) Arrangement of WCs (B) Single row WCs (C) individual showers with changing cubicles

Figure 5.33 Main vertical farm facilities

Source: Neufert, 3rd edition

Table 5.19 WCs Total Area

Facilities	Guidelines	WC units\ (1800*10)	Total area(m^2)
WCs	1 toilet for every 10 to 15 men or 50-100 m^2	180 units	180*2.25= **405**
*Maximum of 10 toilets per facility * 1 wash basin of maximum of 5 WCs			

Source: Neufert, 3rd edition

7. Markets\ shops:

The marketplace will sell some of the goods which the farm produces while the others will be exported outside the country. These shops will be an alternative to using grocery stores.

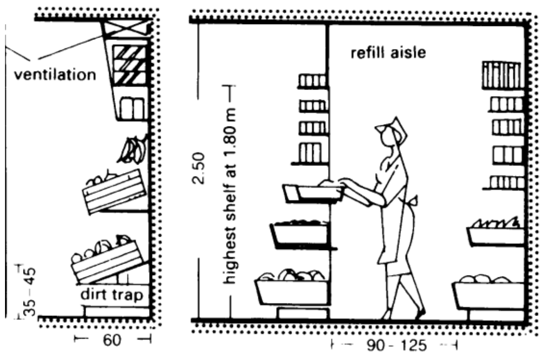


Figure 5.34 Grocery shop dimension, **Source:** Neufert, 3rd edition

8. Mechanical facilities:

Mechanical facilities will include the storage area, central control room, boiler room, digester facilities, and main water storage tank.

- **Storage:**

Storage space will be required to store food which has not been brought into the marketplace, or is being held for upcoming shipment. According to temperature, relative humidity, ethylene productivity or sensitivity of some plants, the vertical farm will have three basement storages units *(see Table 5.20).*

Table 5.20 Main storage classification

Main storages	Refrigerator 1	Refrigerator 2	Storage 3
Crops	lettuce, chicory, parsley, spinach, strawberries	peppers, ripe tomatoes, melon	Mature tomatoes and peppers in the first week after harvesting.
Storage temperature	32 – 40° F	45 – 50° F	Room temperature
Total area(m^2)	**1800**		

Source: the author

- **Control room:**

The vertical-farm environment is regulated from here, allowing for year-round and 24-hour crop cultivation (Chamberlain, April, 2007). The room includes an automated system which aims to use monitors and electronic readers. It can also automatically irrigate and fertilize the plants. The control room will be placed on every floor to make sure that operations are running correctly.

- **Water quantity and resource:**

Water building demand comes from toilets water consumption and plant irrigation; the following *table 5.21* illustrates how much each plant needs water.

Table 5.21 Estimated maximum daily water requirements (H.Jensen and J.Malter, 1995, p.p. 65)

Plant	Liters of water L\m^2	Total area	Total demand (L)
Tomatoes	10	1600*3= 4800	48000 (48 m^3)
Peppers (bedding plant)	20	30*20*2= 1200	24000 (24 m^3)
Melon	20	30*20*2= 1200	24000 (24 m^3)
Strawberries (bench)	15	30*20*2= 1200	18000 (18 m^3)
Lettuce	15	30*20*2= 1200	18000 (18 m^3)
Spinach	15	30*20*2= 1200	18000 (18 m^3)
Chicory	15	30*20*2= 1200	18000 (18 m^3)
Herbs (pot)	20	4*20*30= 2400	48000 (48m^3)
Storage tank capacity	**234,000 L = 234 m^3= 61822 gallon\day**		

Note: US gallon = 0.00378541178 cubic meters

There is another way to calculate water quantity; each plant in a hydroponic system needs approximately 1\2 gallon per day. Water calculation quantity is illustrated in the following *Table 5.22*:

Table 5.22 Water quantity calculations based on 1\2 gallon\plant\day

Vegetable plant	No. of plants\m^2	No. of plant\two floors (30*20*2)	Water quantity 1\2gallon\plant\day
Tomatoes	4	4800	2400
Peppers	4	4800	2400
Melon	4	4800	2400
Strawberries	Two layers 8 plant\m long	9600	4800
Lettuce	16	19200	9600
Spinach	16	19200	9600
Chicory	44.5	52800	26400
Herbs	16	19200	9600
Total		**115200**	**57600 gallon\day**

Both calculations has approximately the same value, this value is the total water consumption of a vertical farm building per day. The volume of the main storage tank should equal 20% plus the calculated water quantity which equals to (75000) gallons.

The (75000) gallon main water storage tank will be located underground in the vertical farm building, which then will feed eleven separate 5620 gallon nutrient tanks,

as each plant will have an individual nutrient solution tank. A pump is used with each system for solution movement. All tank connections, channels and pumps are facilitated with ½" PVC piping. The nutrient solution is renewed every two weeks.

The volume of main water storage tank is (75000*0.0037) 284 m^3, (14*7*3) m (length, width, height) *(see Figure 5.35).*

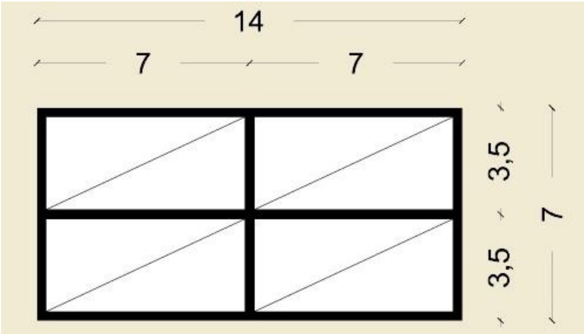


Figure 5.35 Water tank storage

Water resource:

The main source of water supply for the Vertical Farm building will be rain water and adjacent natural resource. Rain water harvesting will be through different types of architectural design elements. The basic model for rain water harvest will be as follows:

The parameters used in estimating total net water harvest are:

- **R:** annual average rainfall which equals 316 mm.
- **A:** building roof area (m^2) which equals 3450 m^2.
- **F:** coefficient of friction factors (.9)
- **FE:** filter efficiency factor (.9)

So, Rainwater harvested quantity:

= R*A*F*FE = 316(R)*3450(A)*.9*.9… (3)

= 883,062 L*.2641

=233,207.1 (gallon), **Note:** 1 liter = 0.264172052 US gallons

9. Summary of program:

In the following *table (5.23)*, is the summary of total building areas.

Table 5.23 Total area of building components

Building program	Area (m^2)
Cultivated\crop field area	**12000**
Packing house	**1600**
Nursery room	**550**
Diagnostic laboratories	**150**
Employee offices	**225**
Employee facilities	**405**
Storage	**1800**
Total area	**16,750+ 20%(circulation area) (3350) = 20100**

5.3.3. Building users:

The building must meet the needs of the users or it will not be fit for purpose. The vertical farming building will include a variety of different users. Plants, and humans (specialists and farmers) are the main users of the building, and both play a role in determining the building layout.

- **Plants:**

It is the only non-human user of the building, but the most important one. Through the building design process, we should meet all the environmental and climatic requirement of each plant. Spaces and functions need to meet the needs of plants are different from spaces designed to meet human needs. Plants entering the building as seeds and leaving as mature fruits go through a specific journey, which is:

Seed → diagnostic laboratory → Nursery (germination) → plant growth field (hydroponic and areoponic) → harvesting (tools and field containers) → packinghouse concept → packaging → storage → transport to the market

Or Residue of plants → digester → bio-gas → power to vertical farm

- **Human user:**

Farmers, researchers, and employees are the main human users of the building, the farmers will be present to harvest, maintain, and process the crops. They will also be present on the first floor marketplace, storage and shipping area. While the researchers will have dedicated lab space to diagnose entered seeds and make sure that operations are running smoothly without any disease contamination.

The larger more efficient greenhouse operation consumes approximately (3) men/acre (7.4 men/ Ha) to operate/maintain the greenhouse and an additional man is needed to package and ship, for a total of (4) men/acre (10 men/ha). The proposed vertical farm building area equals (2) hectares, which need (20) men (14 farmers, 6 men for packaging) to operate the building (Aggie Horticulture, 2005).

5.3.4. Bubble\relationship diagram:

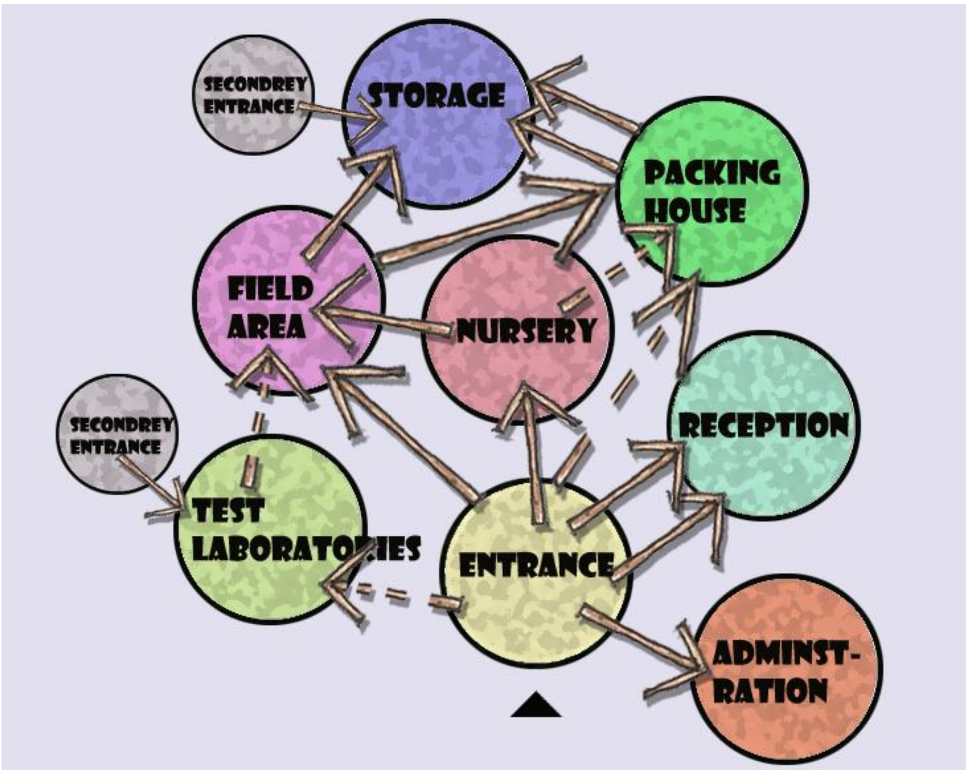


Figure 5.36 Bubble Diagram

5.3.5. Architectural Design Process:

There are three main phases of vertical farm design process. The first being the conceptual design process, which contains the first primitive ideas of vertical farm design concept, such as, what are the main concerns that should be considered in the first phases of the building design, the second is the process of schematic design, which illustrates the main functional zones, space organization, and horizontal and vertical circulation of the building. Finally, the process of design development, which includes the final layout of vertical farm building, plans, elevations, sections, architectural details, and interior and exterior perspectives.

5.3.5.1. Process of Conceptual Design:

In initial stage of development, many ideas were explored on a range of different levels. But there are four main concerns which dominated the whole process of building design and effect the final layout and form of the proposed model of a Vertical Farm building.

(A) First concern, how to capture maximum sunlight:

The project has several program requirements, which can be divided into two main functions. The first one, which is the largest part of the building, is a vertical farm building where the whole operation from cultivation, harvests and packaging is done. The other part is more public, that include the other functions to complete the process of crops production, from plants entering the vertical farm building till the process of mature crops shipping and transported to the local market or exported outside the country. These are nursery rooms, laboratories, admistration, and storage.

The main part of building, the field crop area, should be designed to capture the maximum amount of sunlight, so instead of one massive long building, I proposed to have two buildings, taller and thinner (Vertical Farm 1, and 2) *(see figure 5.37).*

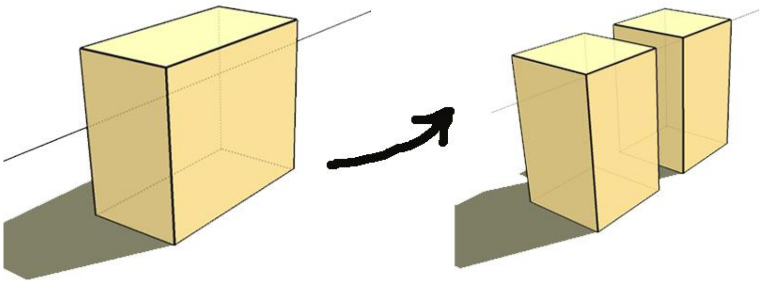


Figure 5. 37 Sketch showing the primary concept design of masses

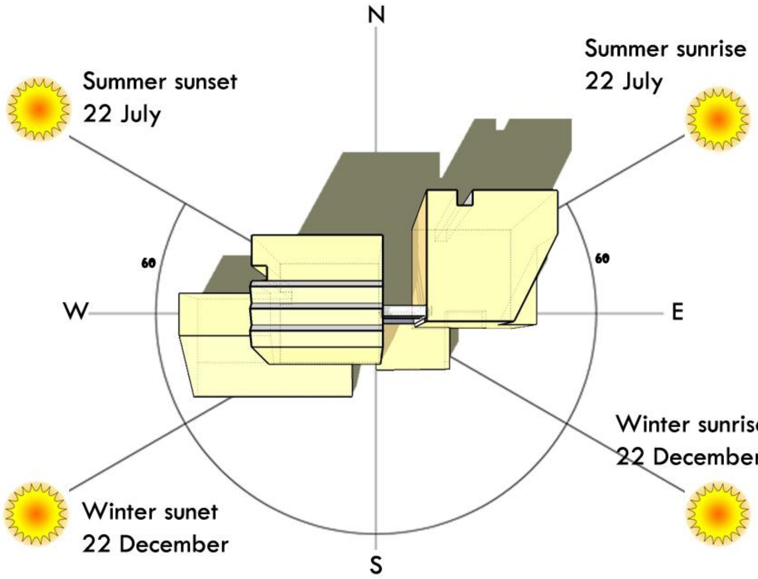


Figure 5.38 Site map showing building orientation to capture maximum sunlight

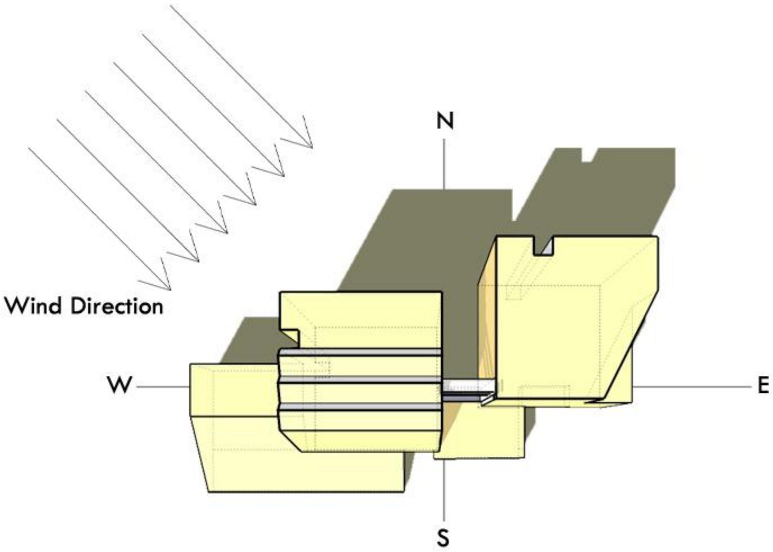


Figure 5.39 Site map showing wind direction

Each building has different kind of crops as illustrated in *(Table 5.24*) Vertical farm one has the warm, hot season crops (tomatoes, peppers, melon, strawberries), which oriented to the south elevation to capture the maximum sunlight in winter and summer, while the other will have the cold, cool season crops (lettuce, spinach, chicory, herbs), and it is oriented to the east south to capture the morning sulight which is enough for cool season plants to grow well *(see figure 5.40).*

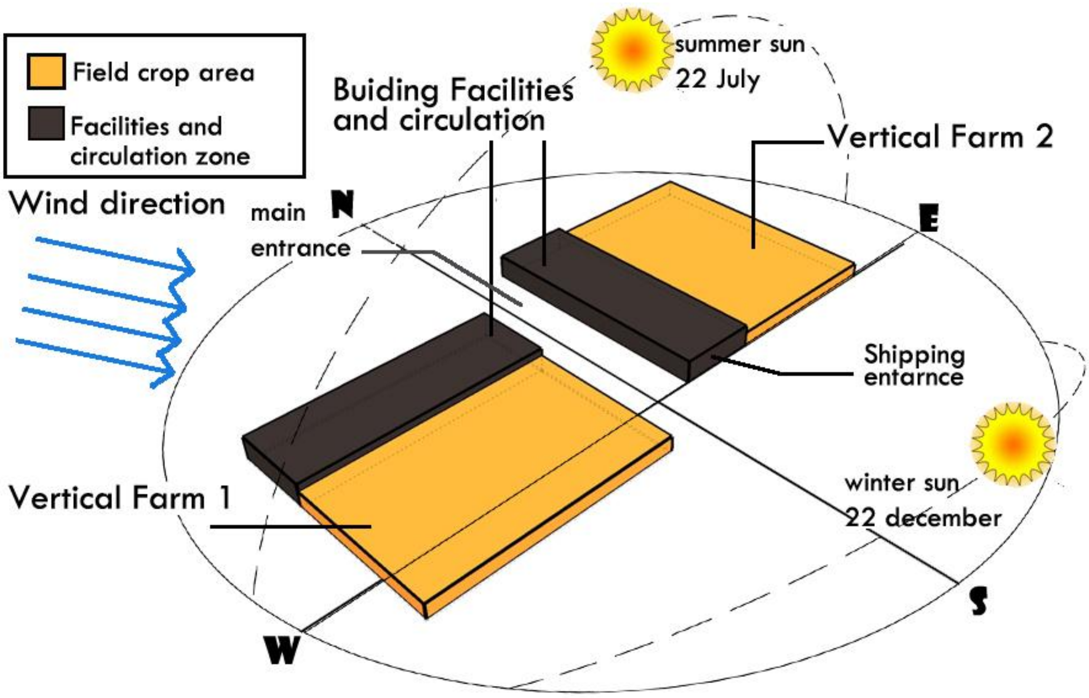


Figure 5.40 Building entrances, main zones

Table 5.24 Vertical farm buildings (one and two) main crops:

Vertical farm 1 (hot and warm season crops)	**Vertical farm 2 (cold and cool seasons crops)**
Tomatoes	Lettuce
Peppers	Spinach
Melon	Chicory
Strawberries	Herbs(basil, thyme, parsley, mint)

As illustrated above, the crops will be distributed horizontally according to the main classification as warm hot season plants in vertical farm one, or cool cold season plants

in vertical farm two. While, vertically, another consideration is taken into account, the hydroponic or aeroponic system will be used for crop cultivation.

Each crop could be cultivated in different hydroponic systems, so in the project the most suitable of hydroponic systems, and most efficient of used space, irrigation water, and nutrient cycle will be used.

Each crop has two floors according to space calculation, except for tomatoes which have three floors, chicory and herbs each has one floor level.

In vertical farm building one, tomatoes, peppers and melons will be cultivated using drip irrigation systems, so they are arranged vertically, and in the upper two floors. Strawberries will be cultivated using benches of NFT hydroponic systems.

In vertical farm two, chicory, lettuce and spinach will be cultivated using the NFT hydroponic system, and in the upper levels, herbs will be cultivated using towers aeroponic system which has the least water consumption *(see figure 5.41).*

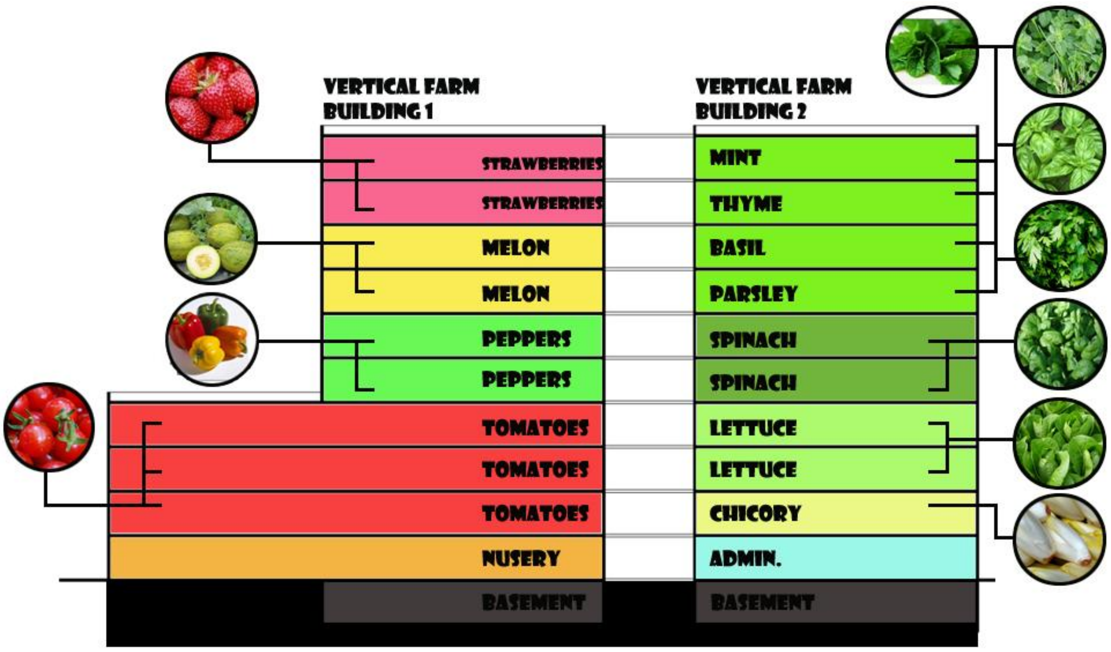


Figure 5.41 Section showing crops vertically distribution in Vertical Farm buildings (1 and 2)

(B) Second concern, plant journey in vertical farm building:

Plant production is the main function of vertical farm building, so the main design intention is to minimize fruits loss by maximizing safety and security of plants from entering the building until shipping and marketing of mature fruits to the market.

So there are additional functions the plant will go through pre-entering vertical farm building. First plants should be tested in labs to make sure that they have no disease. After labs check in, the plant will be transformed to the nursery room for plant germination. It will stay for some days then be transferred to field area production vertically.

When the plant gets matured, it will be harvested and transformed to the packinghouse horizontally through hand truck and trolleys for packaging, then vertically go down to storage in order to keep it in good condition until shipping to the market.

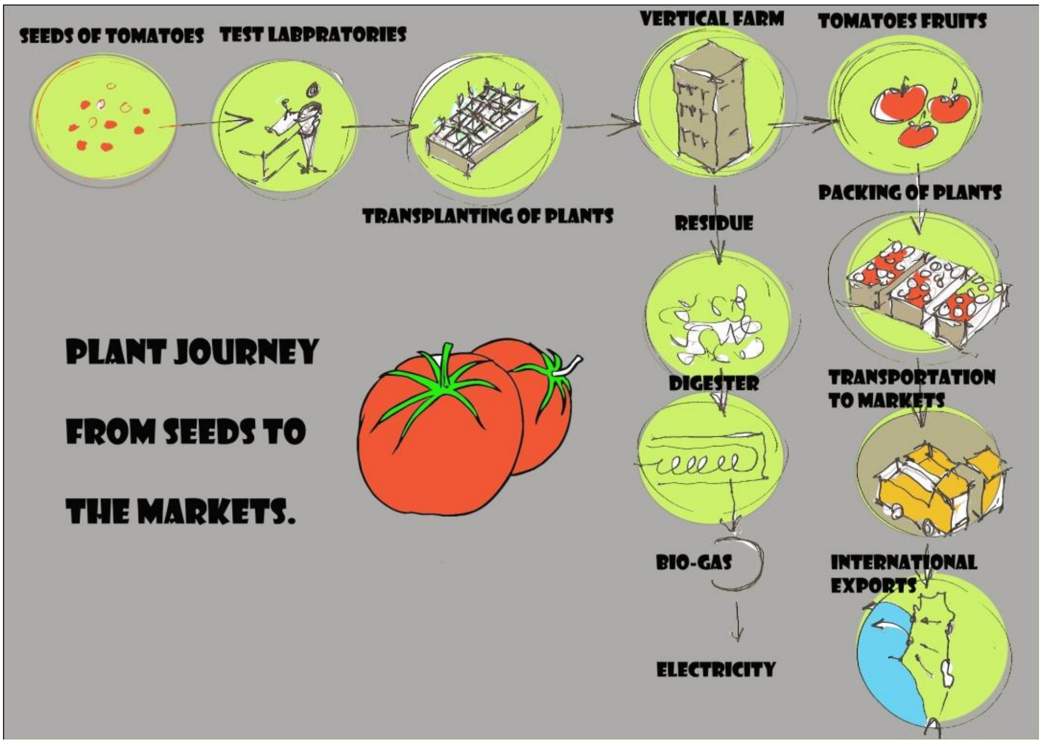


Figure 5.42 sketch showing plant journey from seed to mature fruits (shipping to the market) or residue (produce methane)

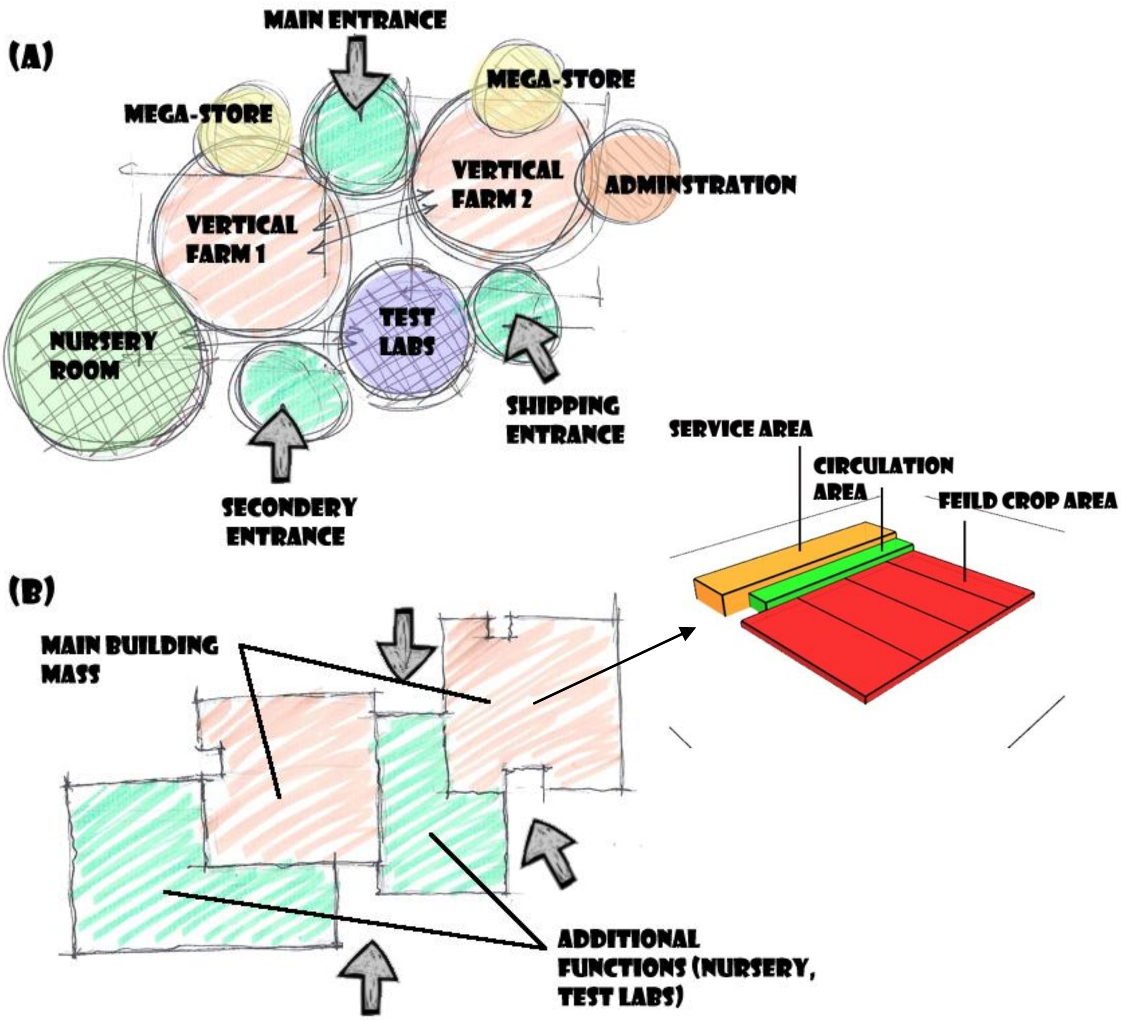


Figure 5.43 Sketch showing main building zones, and building masses

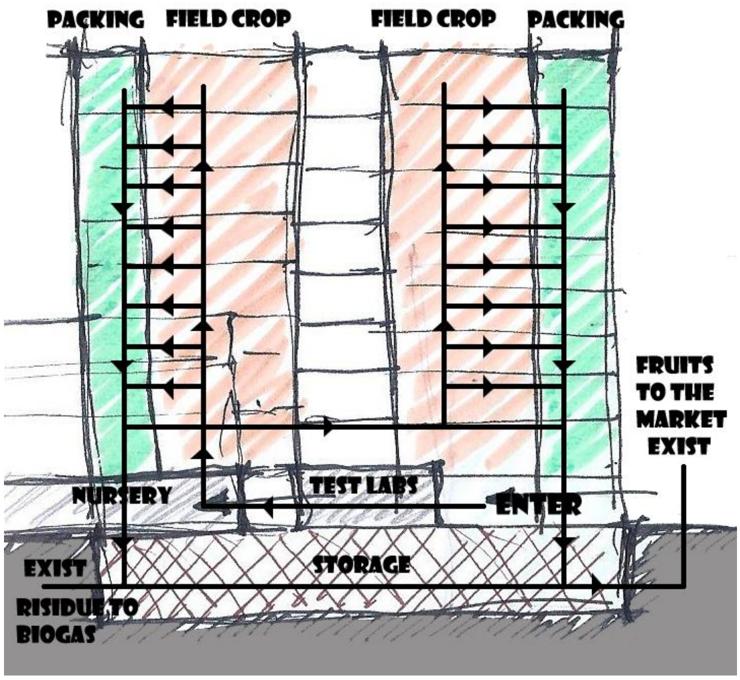


Figure 5.44 Section showing plant journey in the proposed model of vertical farm building

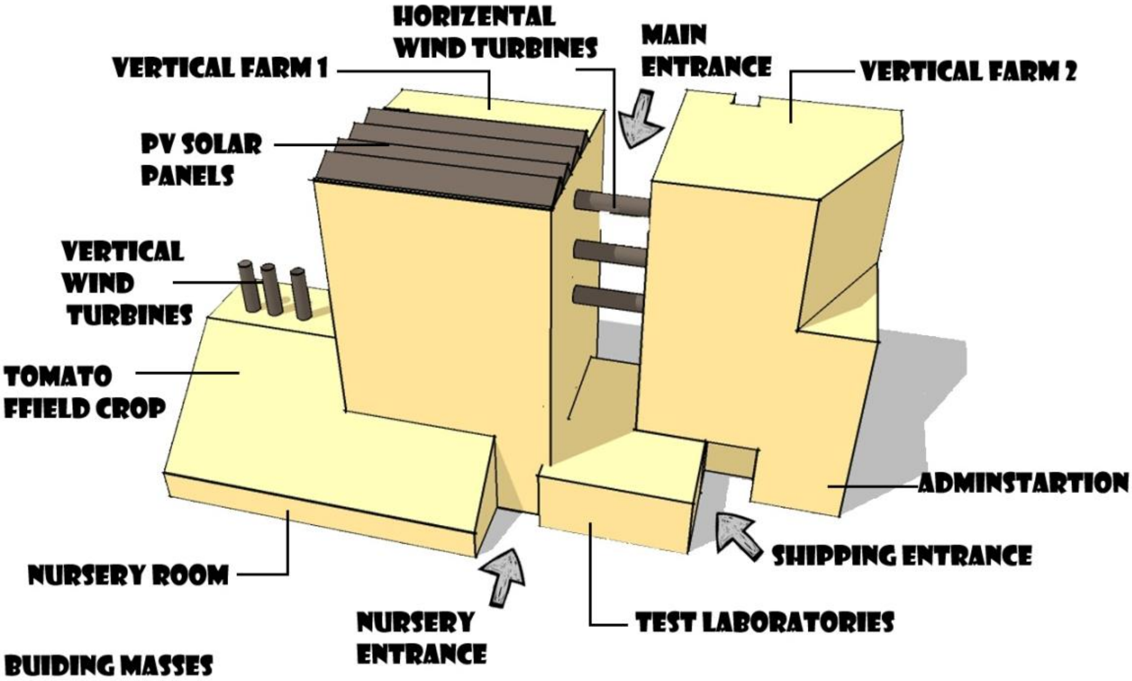


Figure 5.45 3D sketch showing building entrances, and main masses

(C) Third concern, organization of building space will follow ***specific modules:***

It will be in plans, elevations and sections design. Each module will represent a greenhouse unit, the size and height of the module is designed considering many factors:

- **Average size of credible greenhouse unit:**

The dimension of greenhouse should not be more than (50) m x (50) m. Bigger than that, and higher temperatures will build up due to poor ventilation. The length of evaporative cooled greenhouse should not be more than (60) m (TANU, 2008).

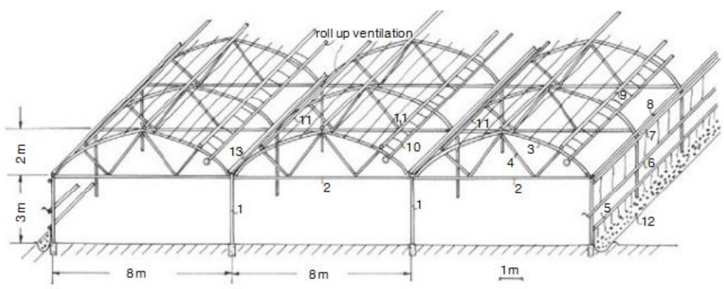


Figure 5.46 Multi span greenhouse in arid regions showing greenhouse modules source: (Zabeltitz**, 2011, p.p. 78)**

- **Sun angle:**

Depending on sun path diagram of the region *(see Figure 5.48),* and by taking sun path in summer (21 July), and sun path in winter (21 December) of the same year at noon, we can determine maximum sun angle by the intersection between the line drawn from the center of the diagram to the noon time and sun path in July and December will determine the circle of vertical sun angle.

Maximum vertical summer sun angle (21 June) equals to (80) degree, while the maximum winter angle (21 December) equals to (30) degree *(see Figure 5.47).*

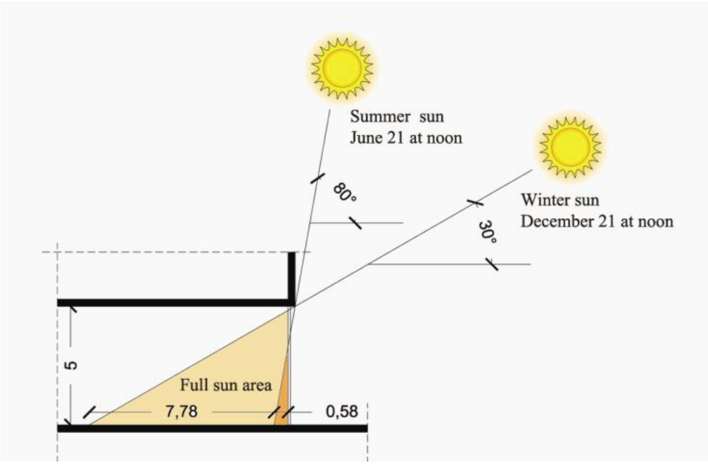


Figure 5.47 Max Sun Angle in winter and summer
source: the author

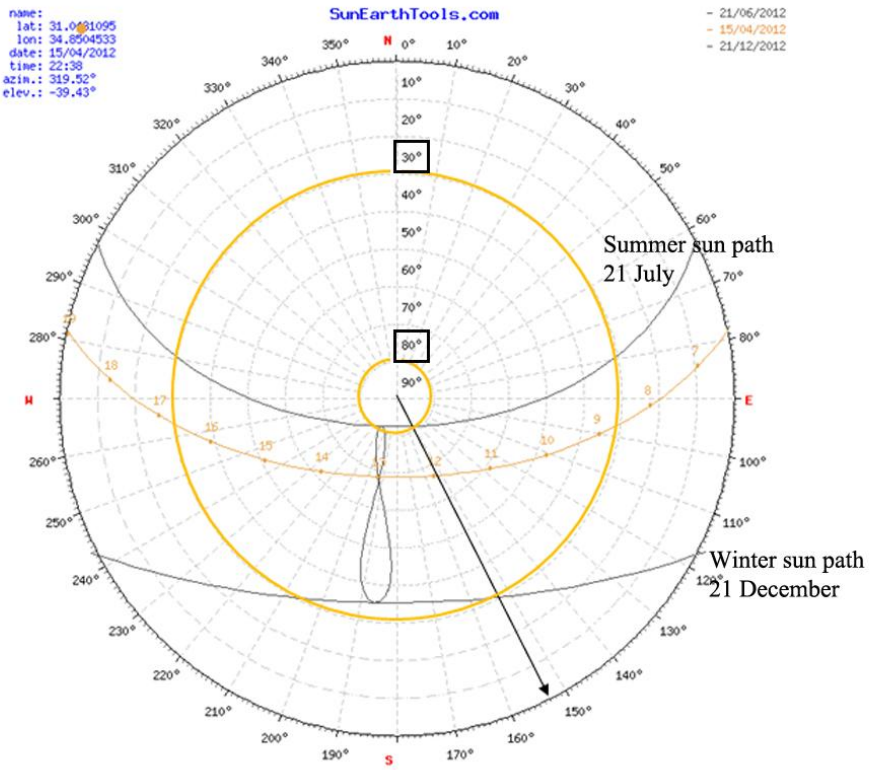


Figure 5.48 Sun Path Diagram in Palestine
Source: http://www.sunearthtools.com/dp/tools/pos_sun.php, retrieved April 15,2012

- **Day lighting:**

To have maximum day light, the room width should be four times the height of the floor with opening on both sides. The height of the building is (5) m, so the room width could reach (20) m ***(see figure 5.49)***.

- **Natural ventilation:**

According to room dimension consideration, natural cross ventilation can be achieved when the width of the room equals five times of the room height. Height of the space is (5) m, so the width should be (5*5) which equals to (25) m long to have cross ventilation.

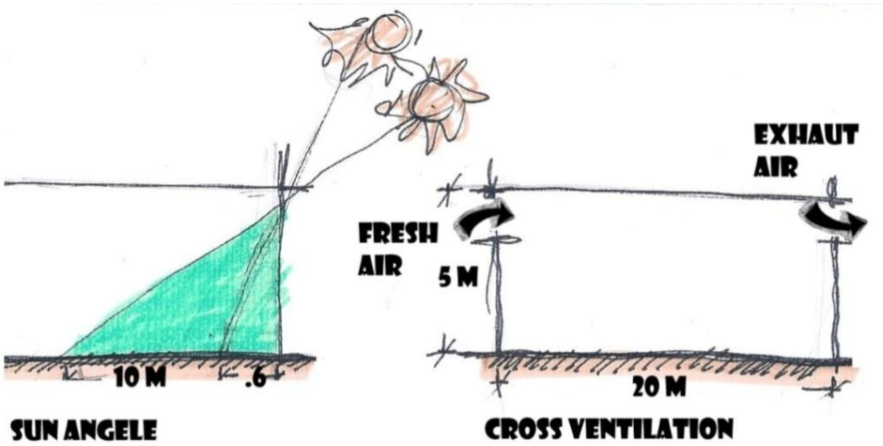


Figure 5.49 Sketches showing sun angle and cross ventilation consideration in vertical farm

- **Construction consideration:**

The span between two columns shouldn't exceed (8) m to have ceiling slab depth of (30) cm and circular columns of (1) m diameter *(see figure 5.50)*.

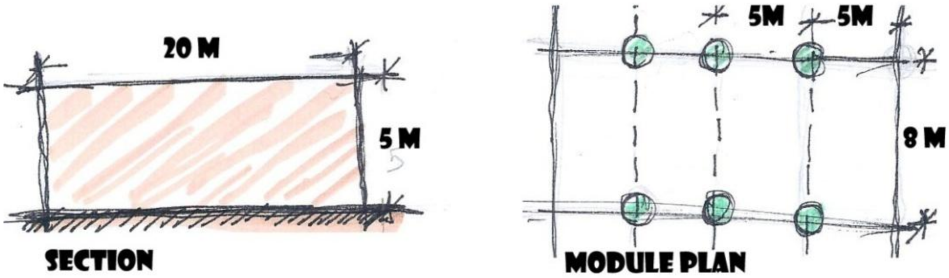


Figure 5.50 Sketches showing the structure module used in vertical farm

The average width of a multi span greenhouse is (8) m, which is suitable for building construction, while the long dimension is (20) m to have good daylight and natural ventilation.

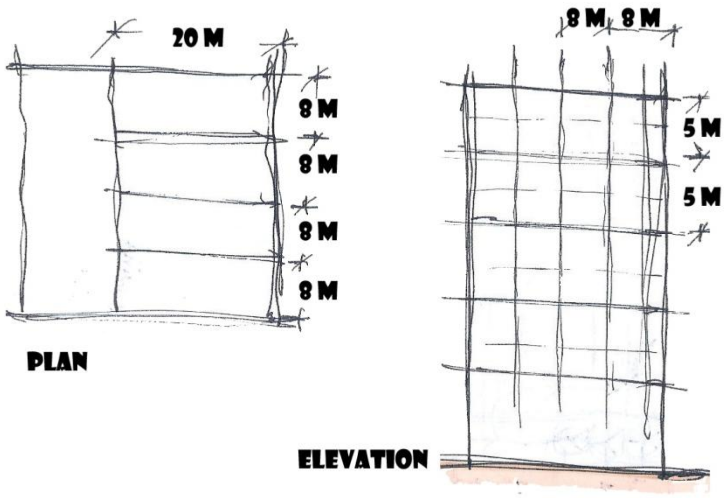


Figure 5.51 sketch showing plan and section module

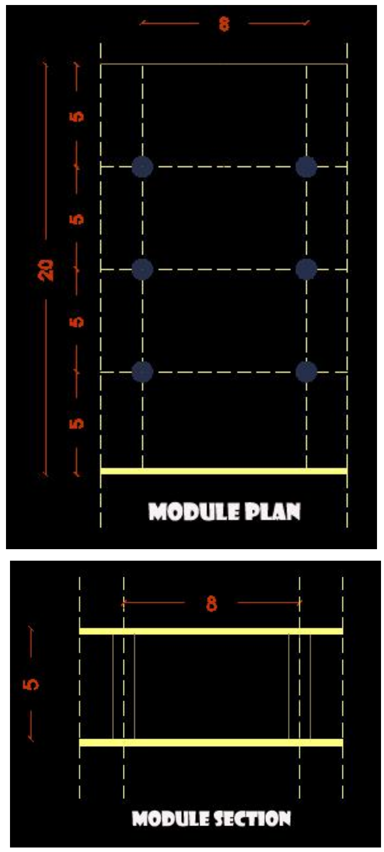


Figure 5.52 module plan and section

(D) Fourth concern, how to capture renewable energy, sun power, wind power, and biogas?

Wind power is the main renewable energy source to generate power for both vertical farm building; it is used to generate electricity for pumps used in water irrigation system. Three horizontal wind turbines will be located between vertical farm building one and two, while the other three vertical wind turbines will be located in the roof of the additional building ***(see figure 5.53)***.

PV solar panels will be installed in the roof of vertical farm building one, this system will be used for heating the water tank system that will keep building warm in winter, the hot water will distribute through pipes under the beds of crops or between them to heat the surrounding environment.

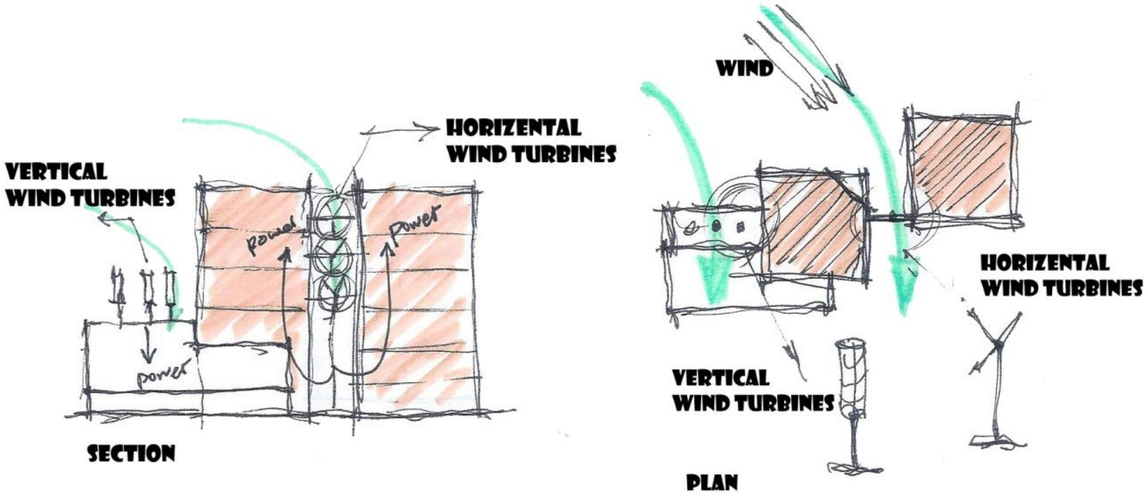


Figure 5.53 Sketch showing vertical and horizental wind turbines integrated in building design

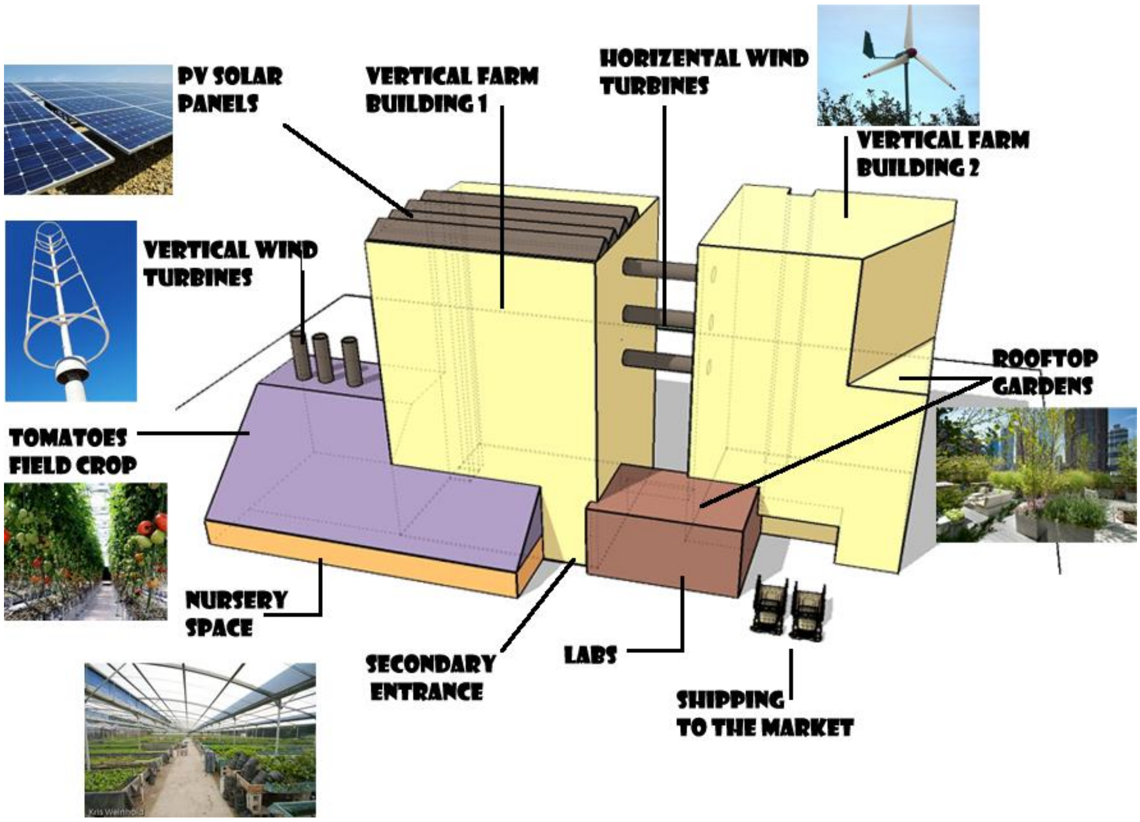


Figure 5.54 3D sketch showing different technologies integrated in vertical farm design

In the following will be the Initial sketches of the proposed model of vertical farm:

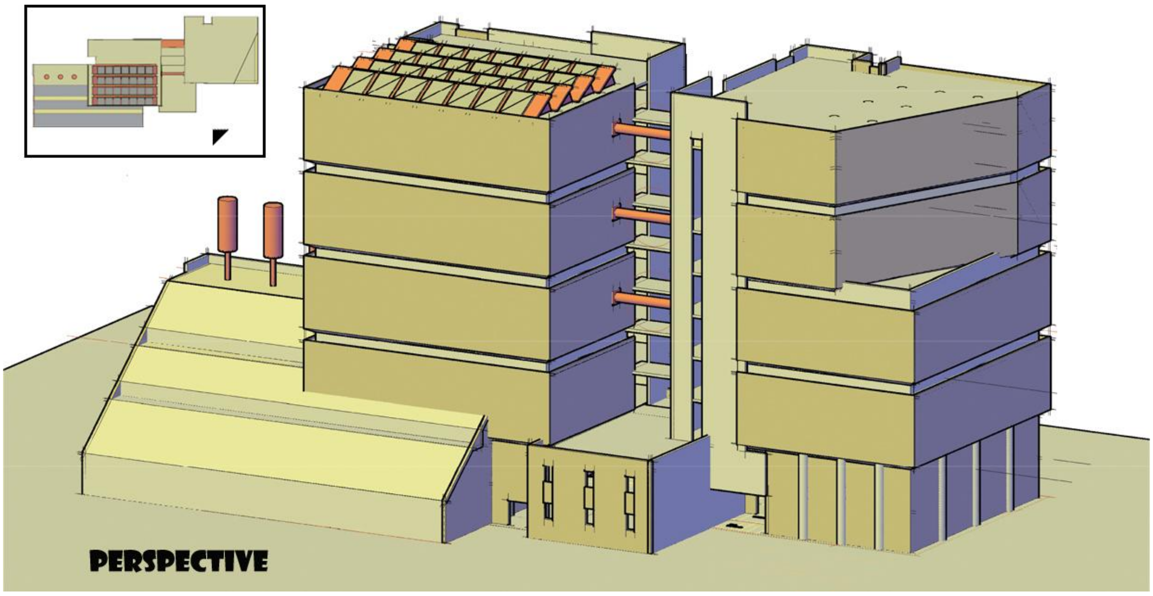


Figure 5.55 View from south east elevation, showing final sketch of vertical farm in phase 1

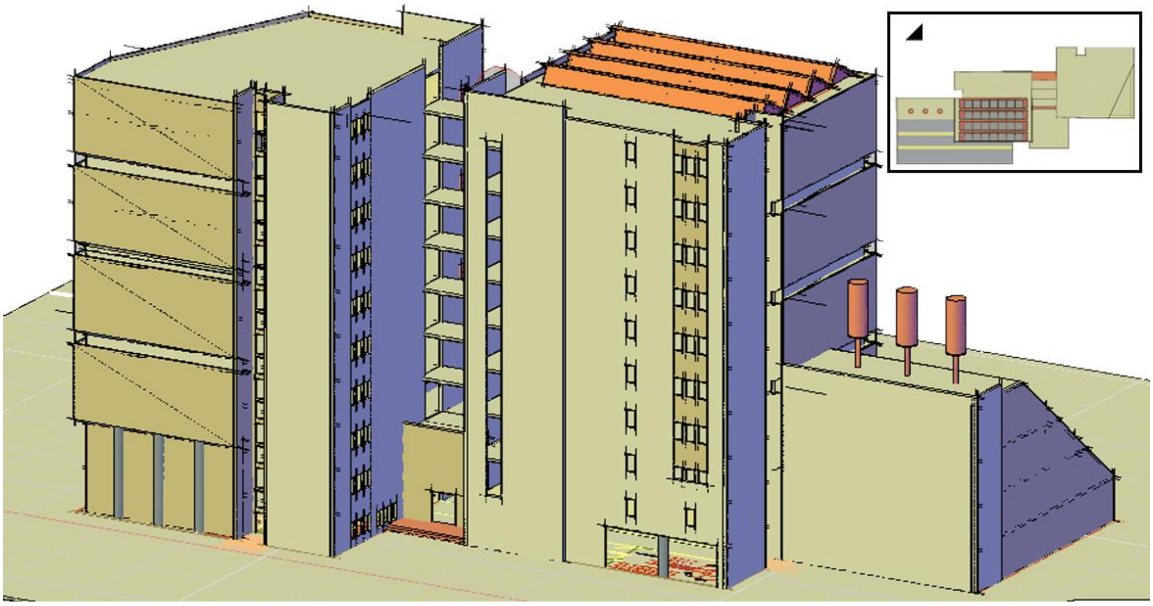


Figure 5.56 View from west north elevation, showing final sketch of vertical farm in phase 1

5.3.5.2. Process of Schematic Design:

In the second stage of the design process, the designers' intention was to integrate all the ideas and strategies into a single coherent design scheme. First, I start to translate the main schematic zones and the basic programmatic relationships into horizontal and

vertical arrangement of functions by considering plant and human circulation in the building from entry to exist. Also water and waste cycle in the building will be considered in the design process ***(see figure 5.57, 5.58)***.

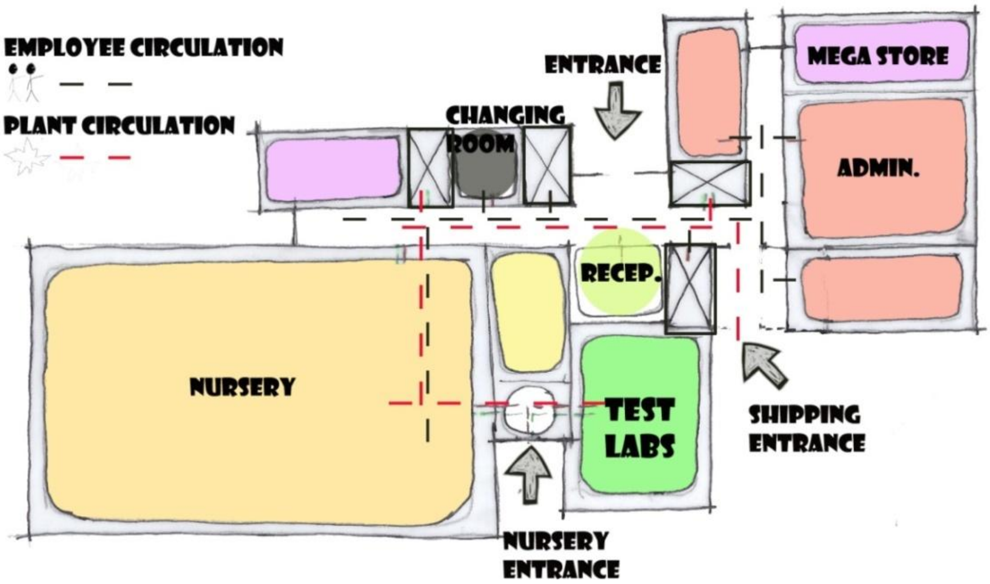


Figure 5.57 Plan sketch showing human and plant circulation, and spaces organization in ground floor plan

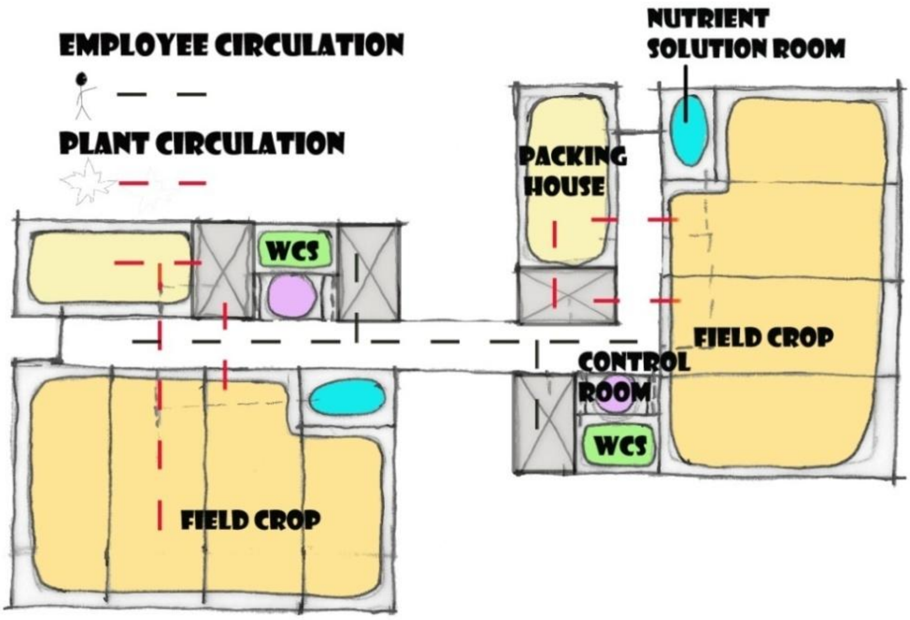


Figure 5.58 Plan sketch showing human and plant circulation, and spaces organization in typical floor plan

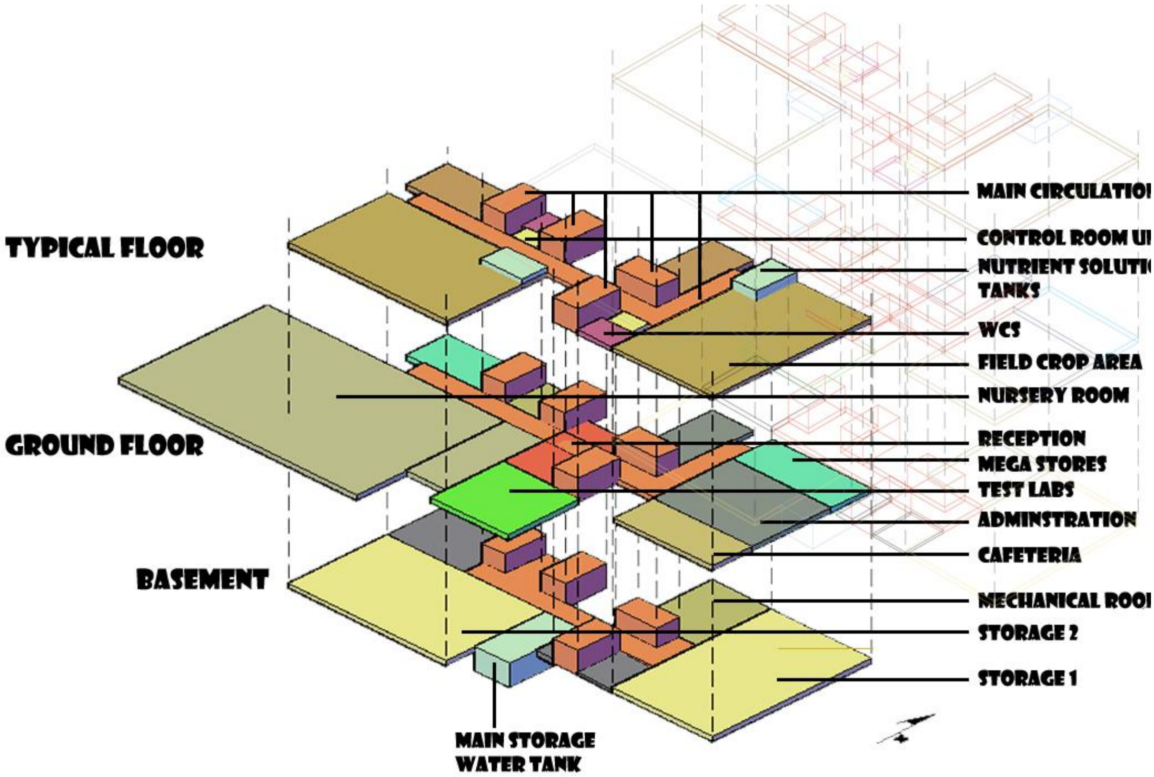


Figure 5.59 Building vertical and horizontal spaces

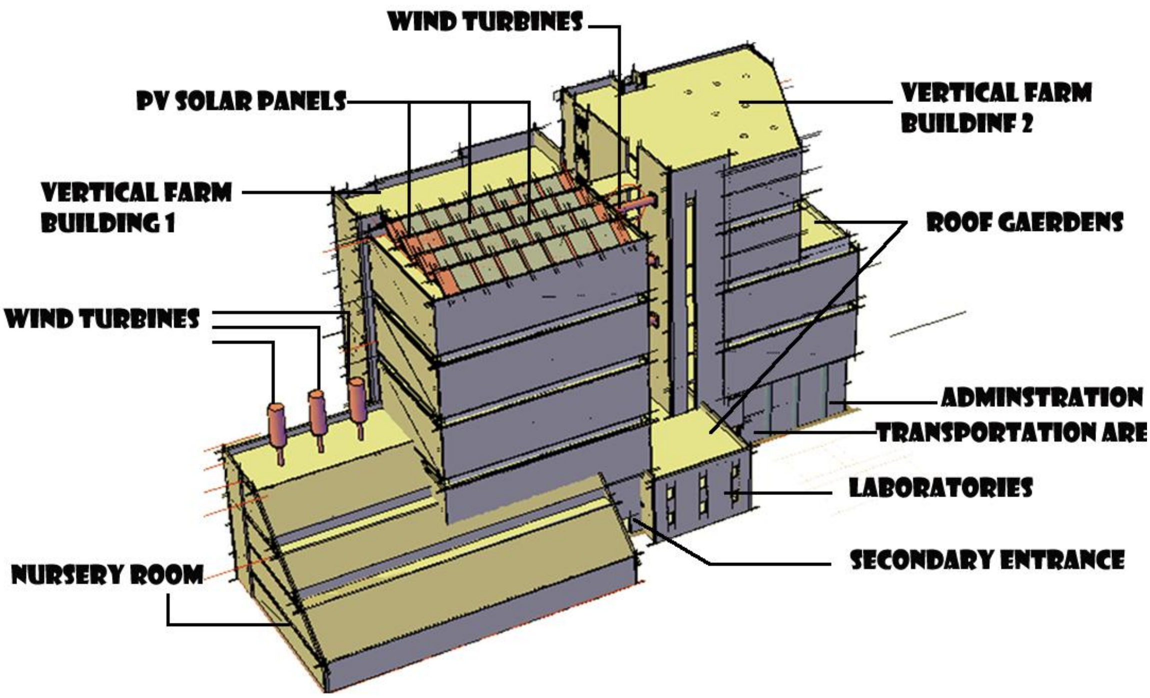


Figure 5.60 Perspective sketch showing the development of building design in the second phase

In the following *figures (5.61, 5.62)* will be some of pre-final sketches of the proposed model of vertical farm building.

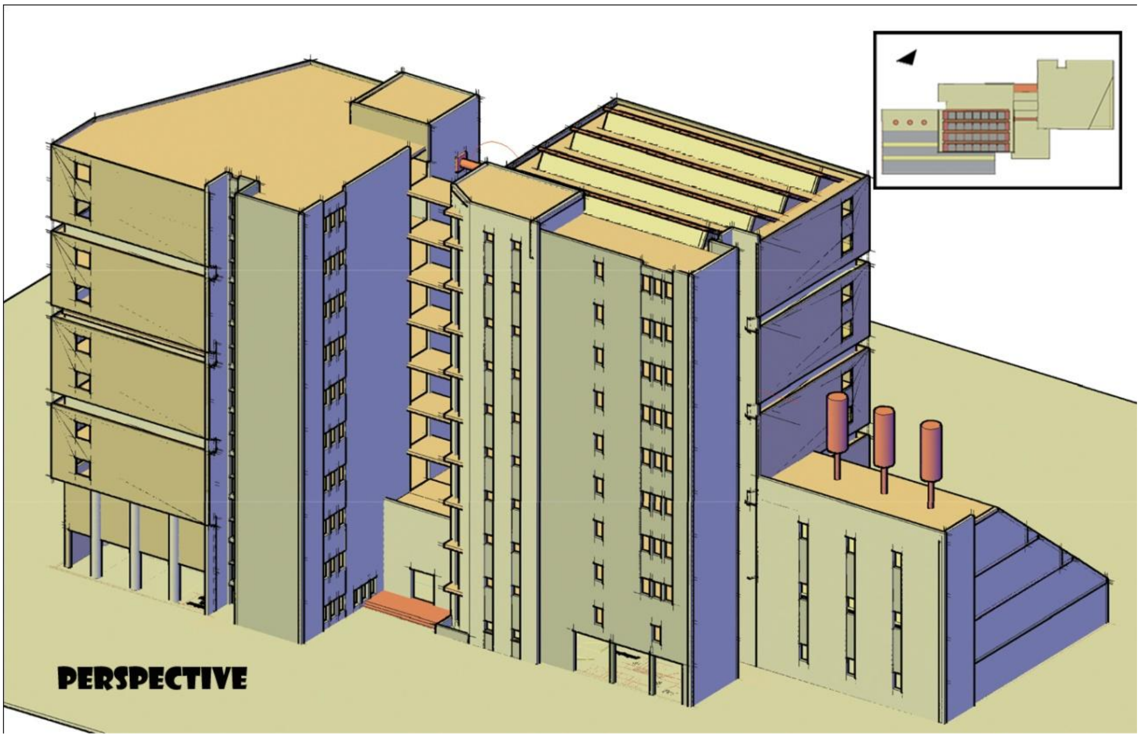


Figure 5.61 Perspective sketch showing the west north elevation of proposed model of vertical farm building in phase 2

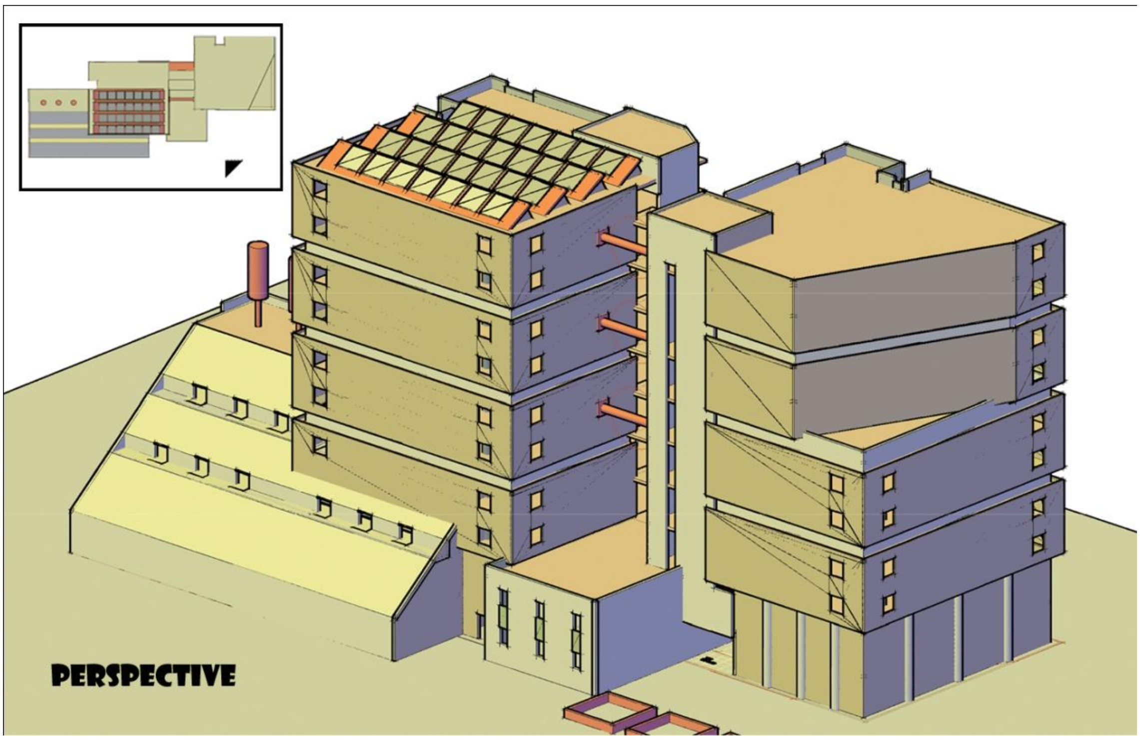


Figure 5.62 Perspective sketch showing the east south elevation of proposed model of vertical farm building in phase 2

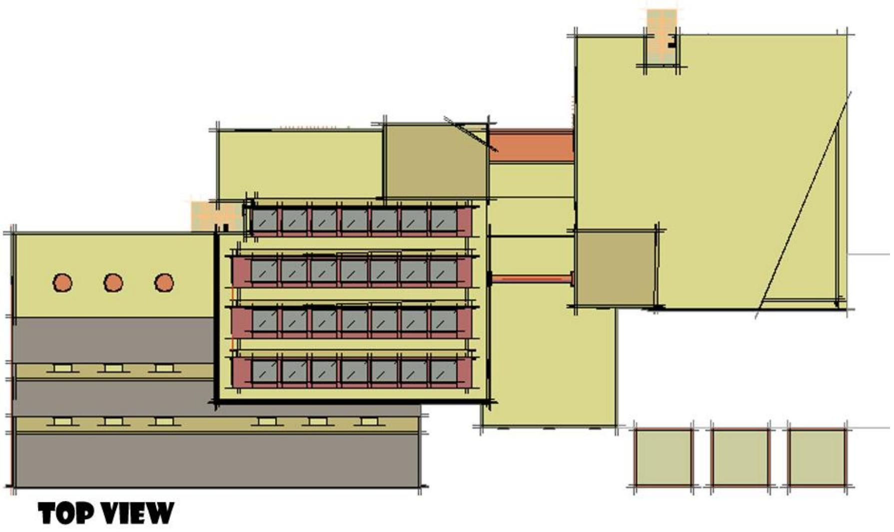


Figure 5.63 Top view

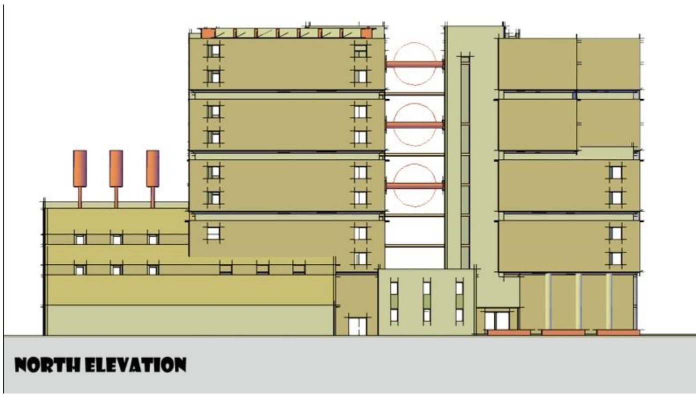


Figure 5.64 South elevation

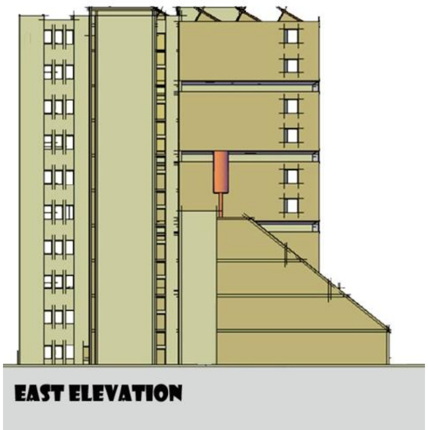


Figure 5.65 East elevation

Figure 5.66 North elevation

Figure 5.67 West elevation

5.3.5.3. Process of Design Development / Architectural drawing:

This is the third phase of design process, and the following pages will introduce the final architectural drawings of plans, elevations, sections, and architectural details. And the architectural drawings of building water, natural ventilation and energy cycles.

(A) Site plan:

The proposed vertical farm is situated in the best location discussed in section one of chapter five. The site is flat area; the surrounding market from the south is one floor height.

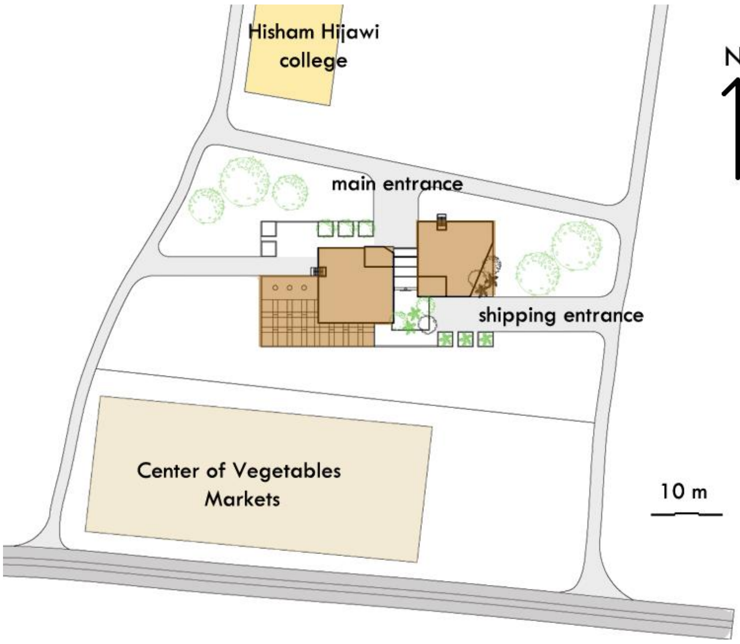
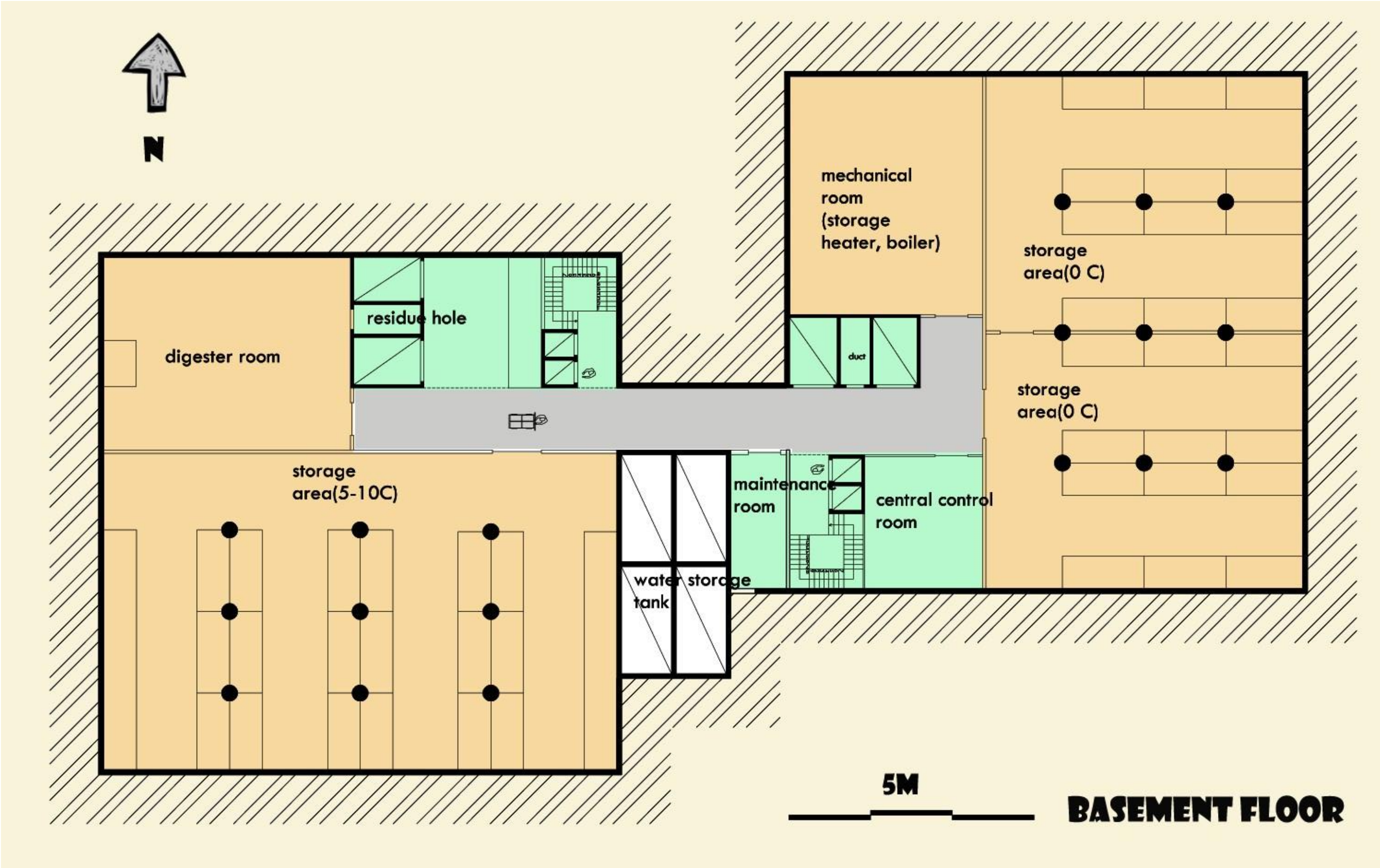


Figure 5.68 Site plan showing the proposed vertical farm within the context

(B) Plans:

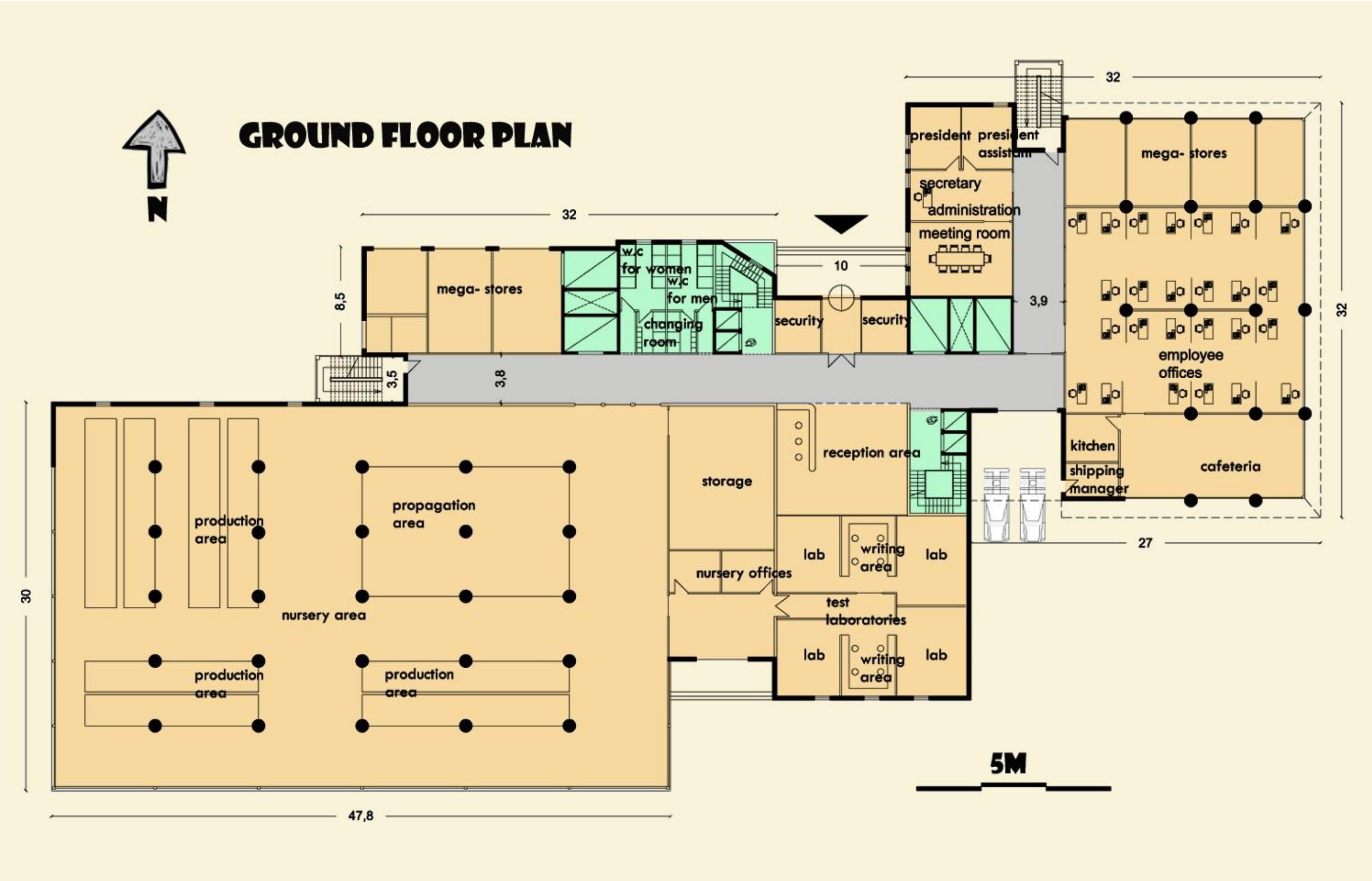
The building has ten floors with a basement. Each floor has specific crop to cultivate.

- The basement will be the storage, mechanical room, and digester room.
- The ground floor will have the main entrance, reception, nursery room, test laboratories, administration, and mega stores.
- First, second, third floors will have the packing house room and the field crops of tomatoes, chicory, and lettuce.
- Fourth, fifth, sixth, seventh, eighth, and ninth floor will have the field crops of peppers, muskmelon, strawberries, spinach, and herbs.



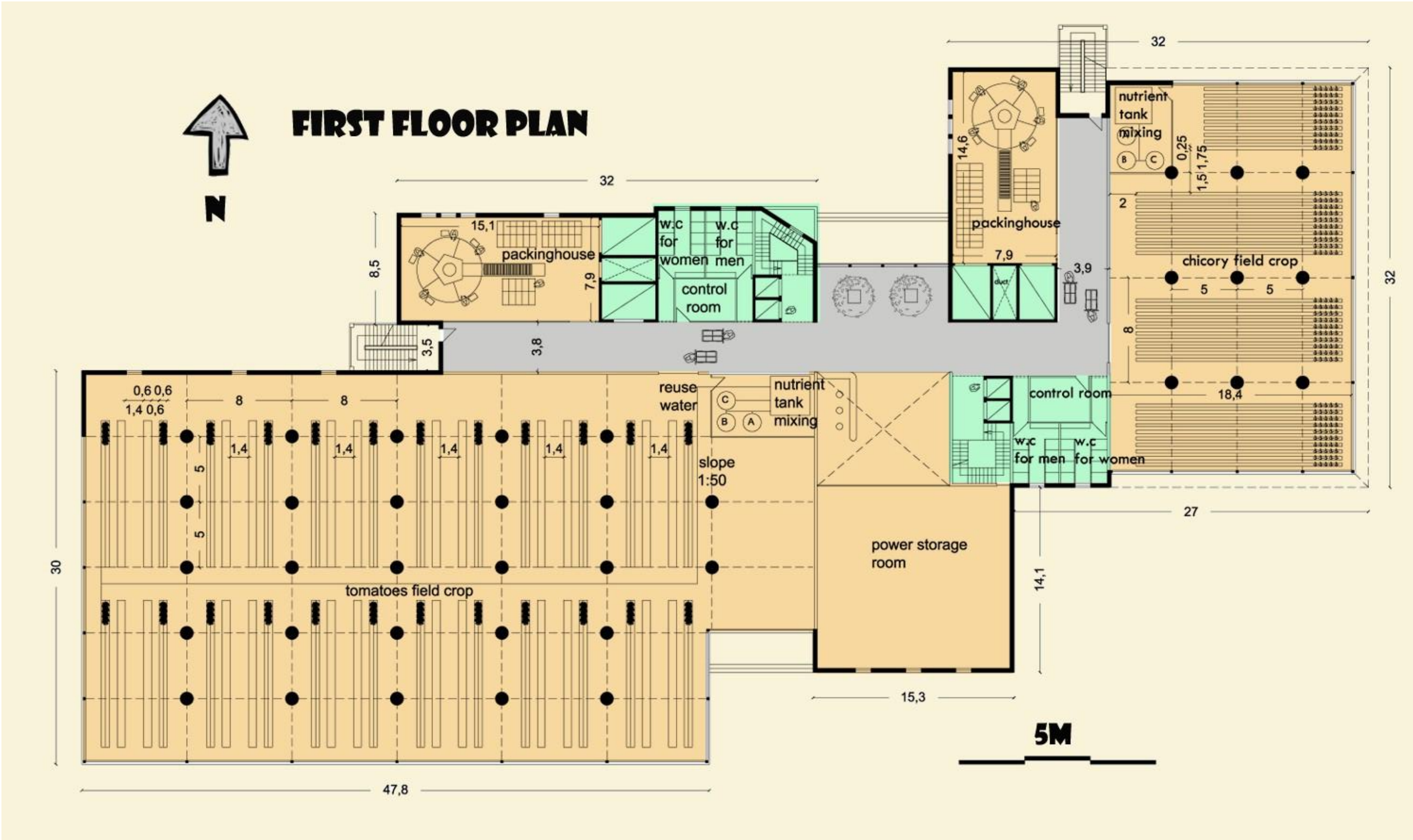
There are two storage rooms *(in orange colour)*, one located in vertcal farm one to store goods in room temprature (5-10^{o}C), while the other is located in building 2 as a refrigerator. The mechnical room (hot water tank and boiler) is located in Vertical farm two. Digester room is located in vertical farm one.

Figure 5.69 Basement floor plan



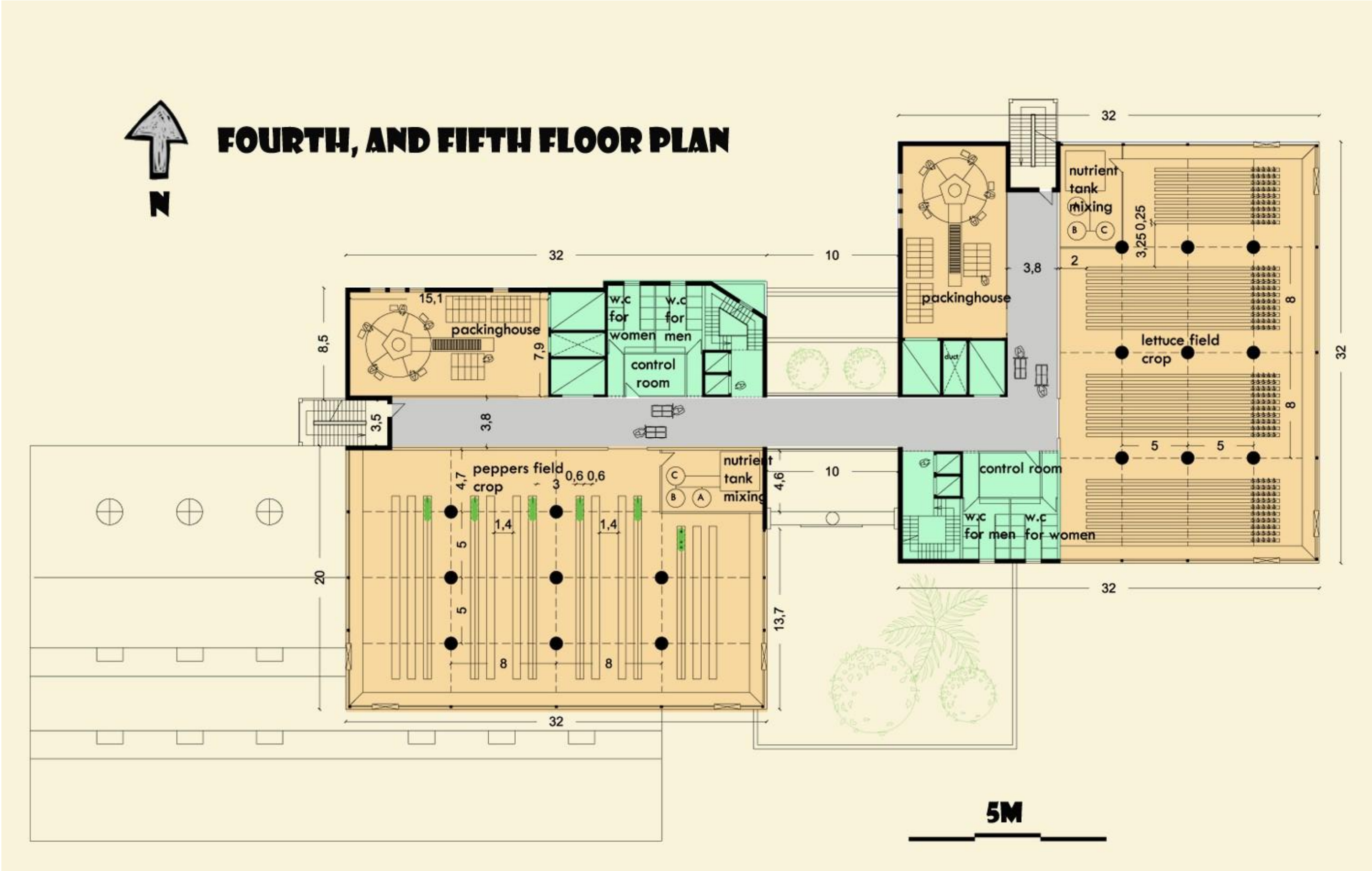
Moving to ground floor plan in left figure. The main entry to the vertical farm is located in the upper part of floor plan. The farmers should first enter the changing rooms located next to stairwell. There are two main stairwells, in both vertical farm buildings one and two. The passenger elevator is next to the stairwells, while the elevators of harvested goods are located next to the main circulation corridor *(in grey colour)*. Adminstration, test labs, maketshops, and nursery roon are the main spaces of this

Figure 5.70 Ground Floor plan



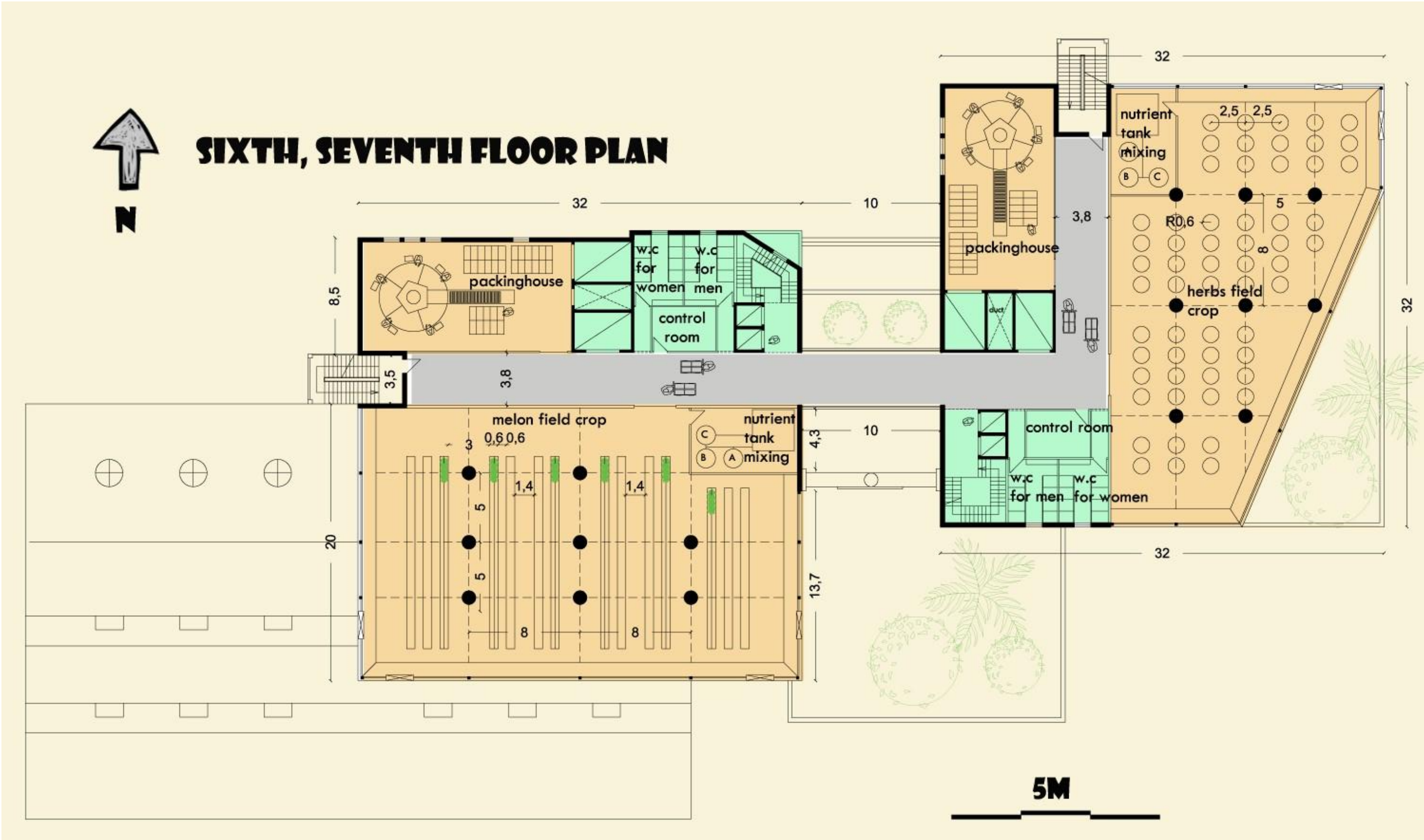
The ground floor plan has both, the chicory field crop at the right, and the tomatoes field crop at left, with packinghouse units in both building.

Figure 5.71 First Floor plan



Fourth and fifth floor plans have the same field crops of lettuce at the right side, and peppers at the left side. With packinghouse units in both building.

Figure 5.72 Fourth and Fifth Floor plan



Sixth and seventh floor plans have the same field crops of herbs at the right side, and watermelon at the left side. With packinghouse units in both building.

Figure 5.73 sixth, seventh Floor plan

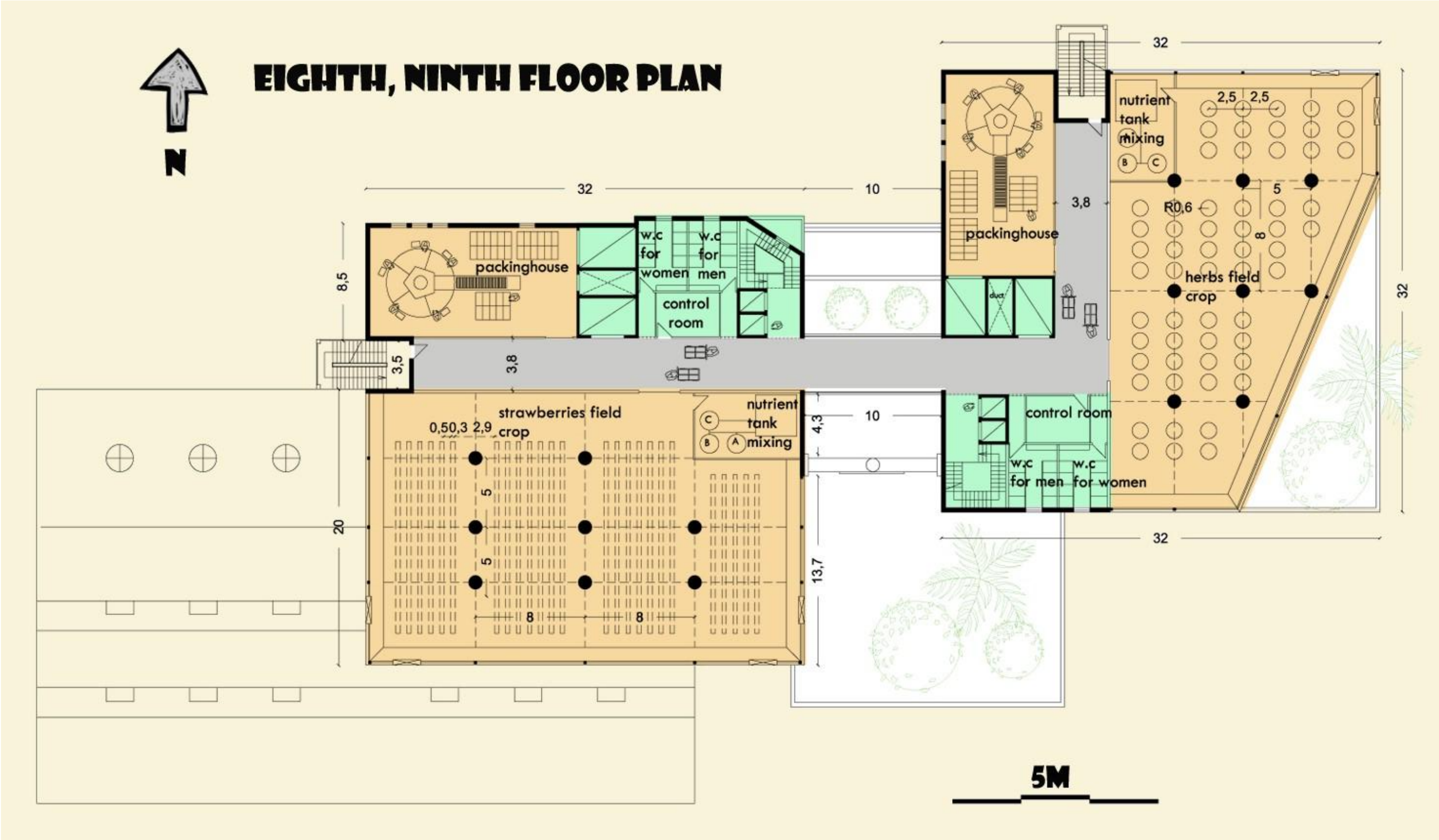


Figure 5.74 eighth and ninth Floor plan

Eighth and ninth floor plans have the same field crops of herbs at the right side, and strawberries at the left side. With packinghouse units in both building.

(C) Sections:

In the following pages, there are two sections, section A-A, and section B-B as illustrated in the ground floor plan.

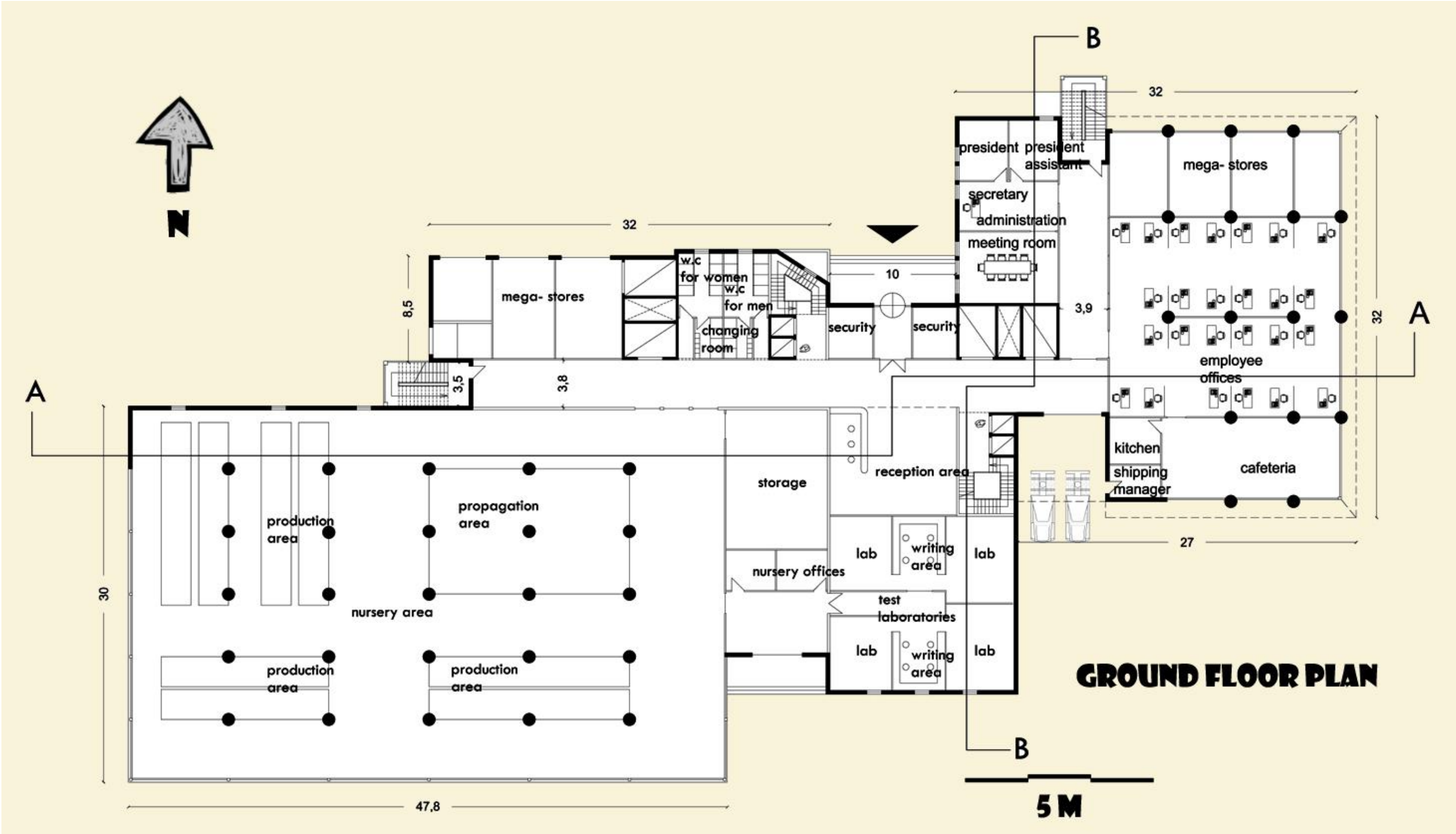


Figure 5.75 ground Floor plan showing section A-A, and section B-B

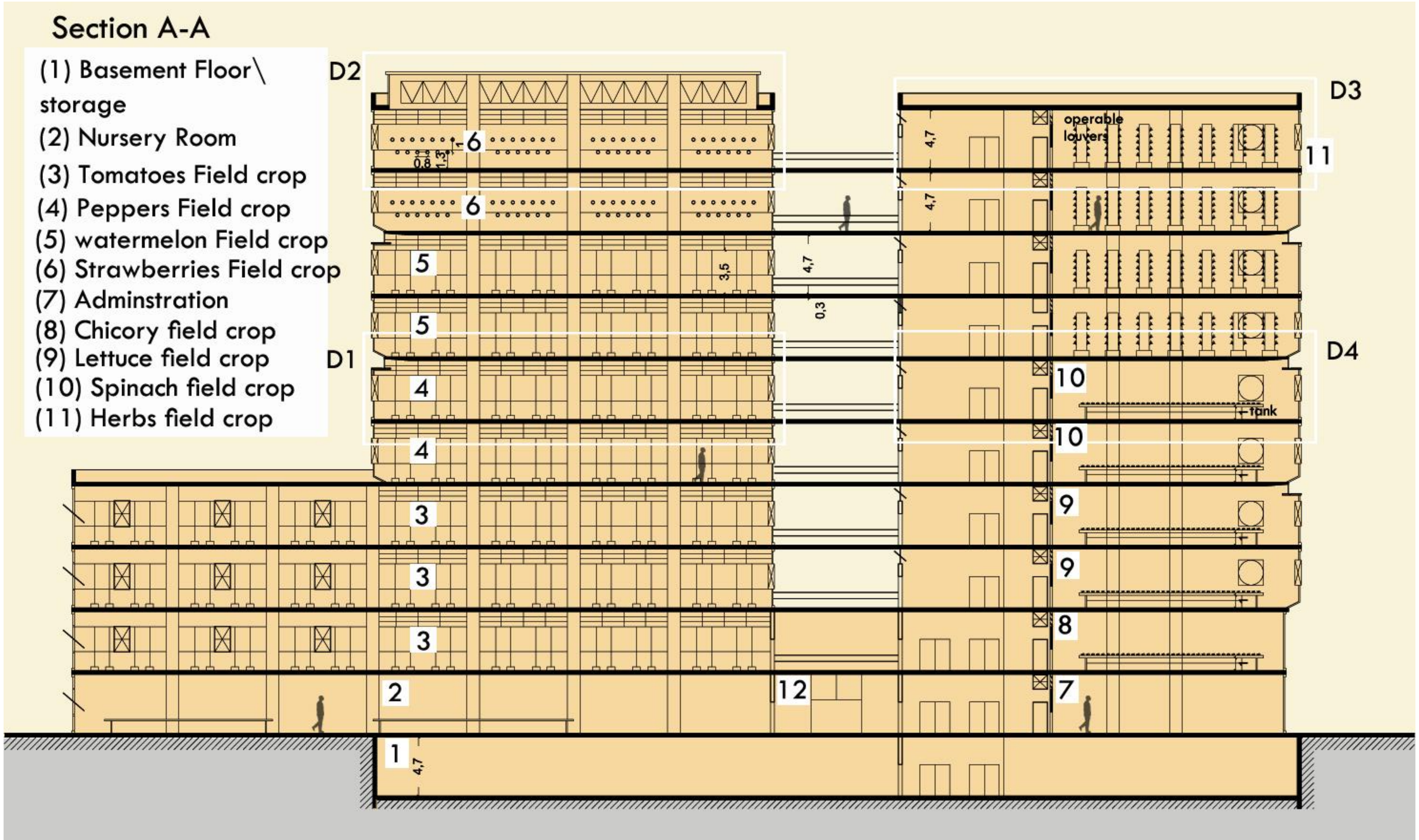


Figure 5.76 Section A-A

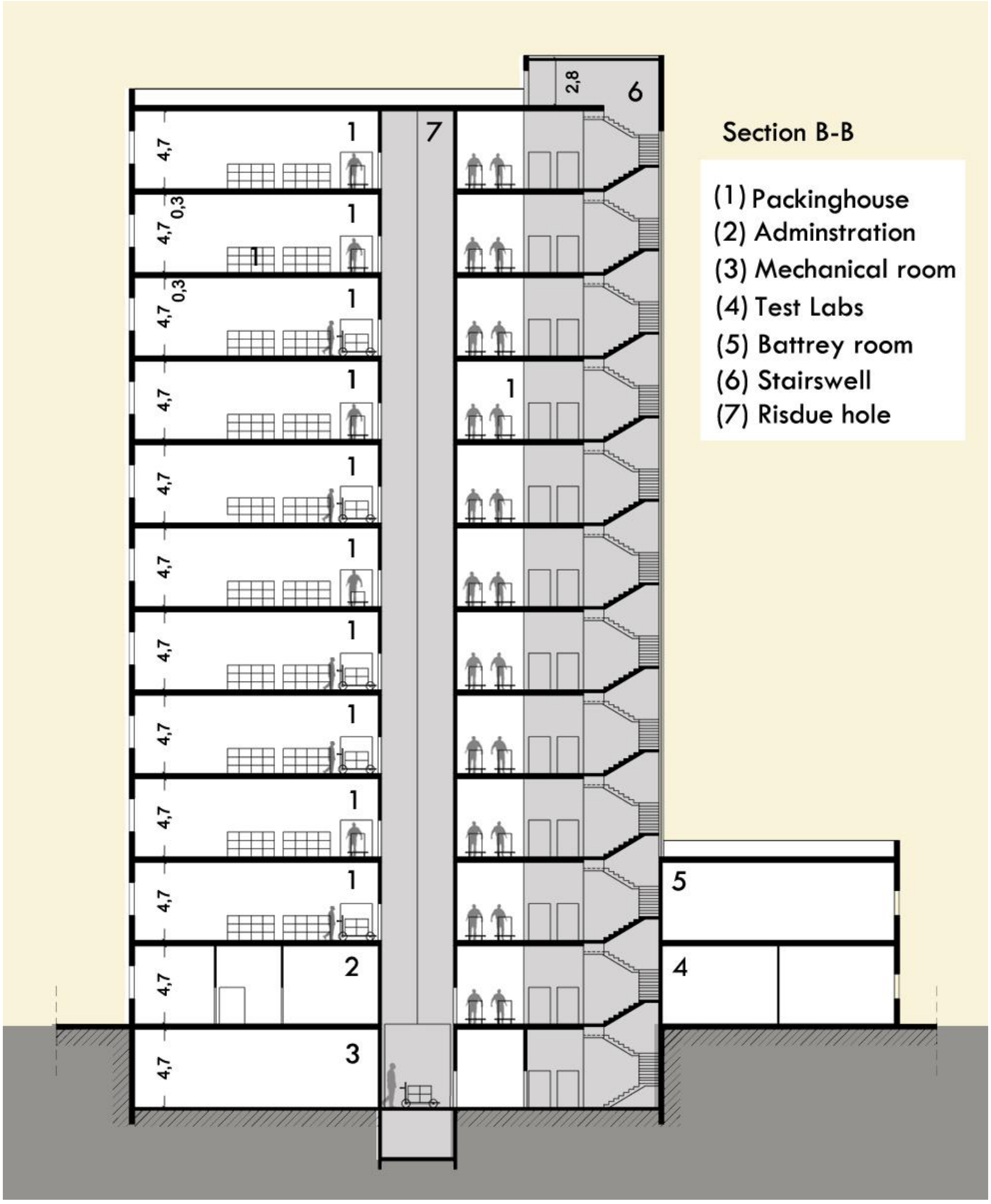


Figure 5.77 Section B-B showing packing process and plant waste collection through vertical hole

(D) Hydroponic System Details:

There are four main hydroponic systems are used in crops cultivation:

- Drip irrigation system for tomatoes, pepper, and watermelon.
- NFT hydroponic hanging channels for strawberries.
- NFT hydroponics channels for chicory, lettuce, and spinach.
- Tower aeroponic system for herbs.

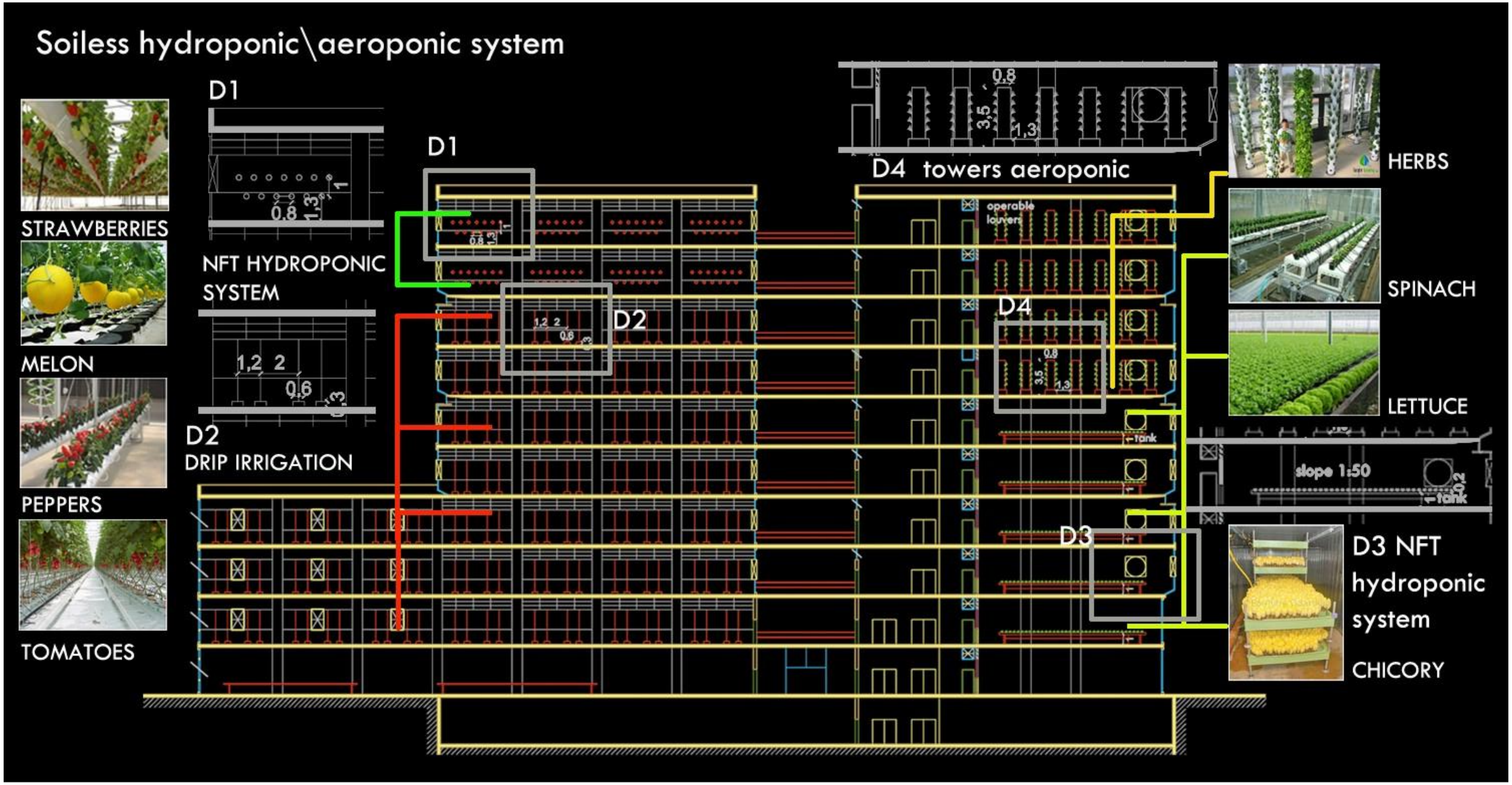


Figure 5.78 Hydroponic system used in crops cultivation

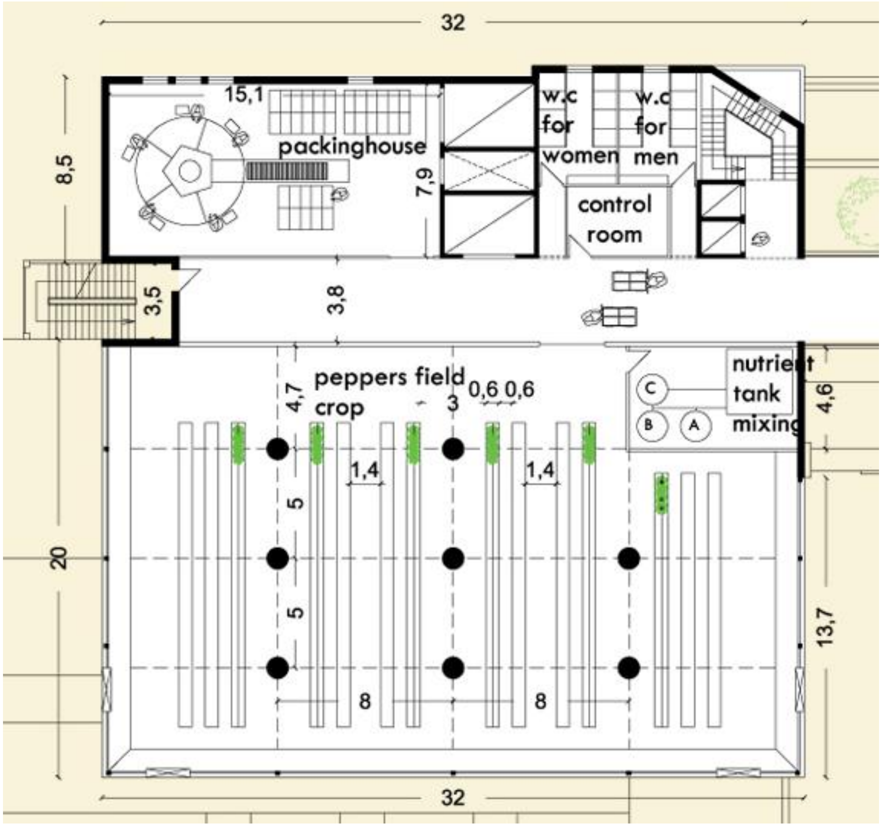


Figure 5.79 Typical floor plan showing tomatoes, pepper, and watermelon field arrangement

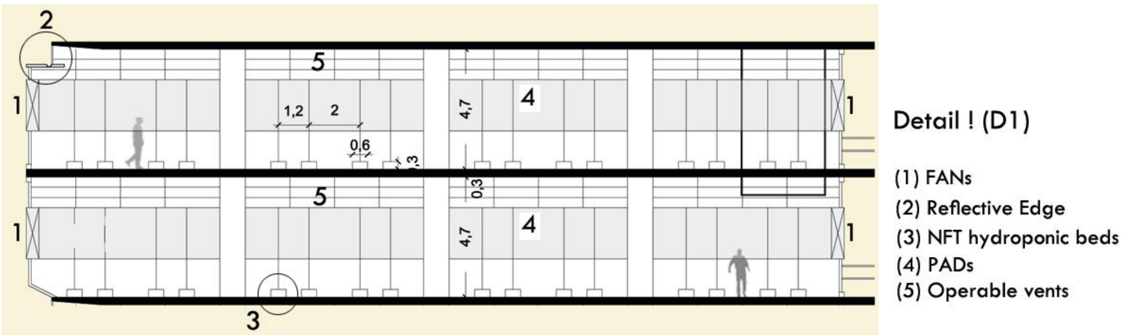


Figure 5.80 D1 showing NFT hydroponic beds

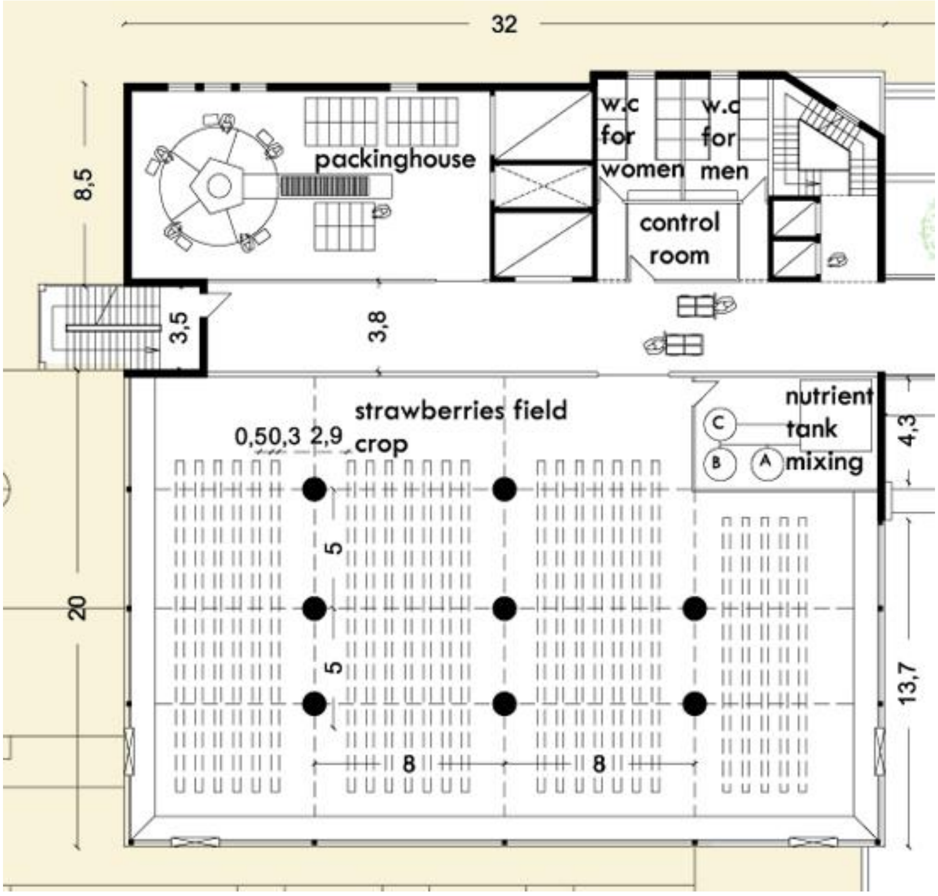


Figure 5.81 Typical floor plan showing strawberries field arrangement

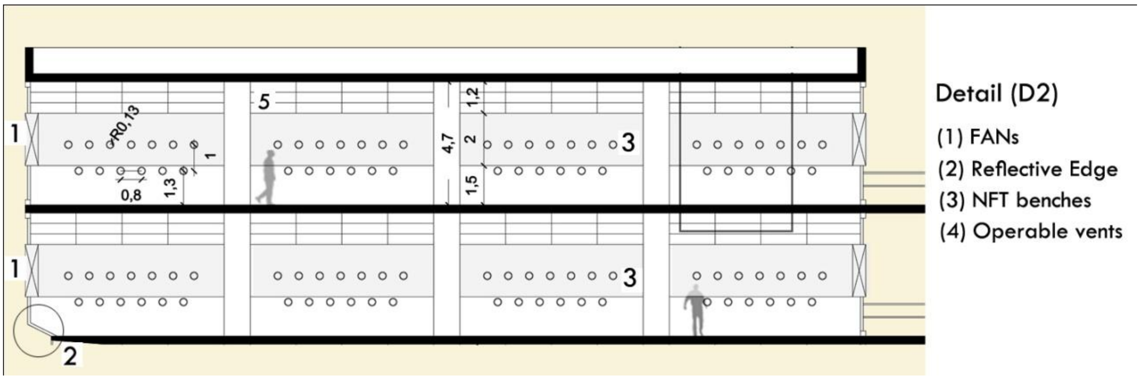


Figure 5.82 D2 showing NFT hydroponic benches of strawberries

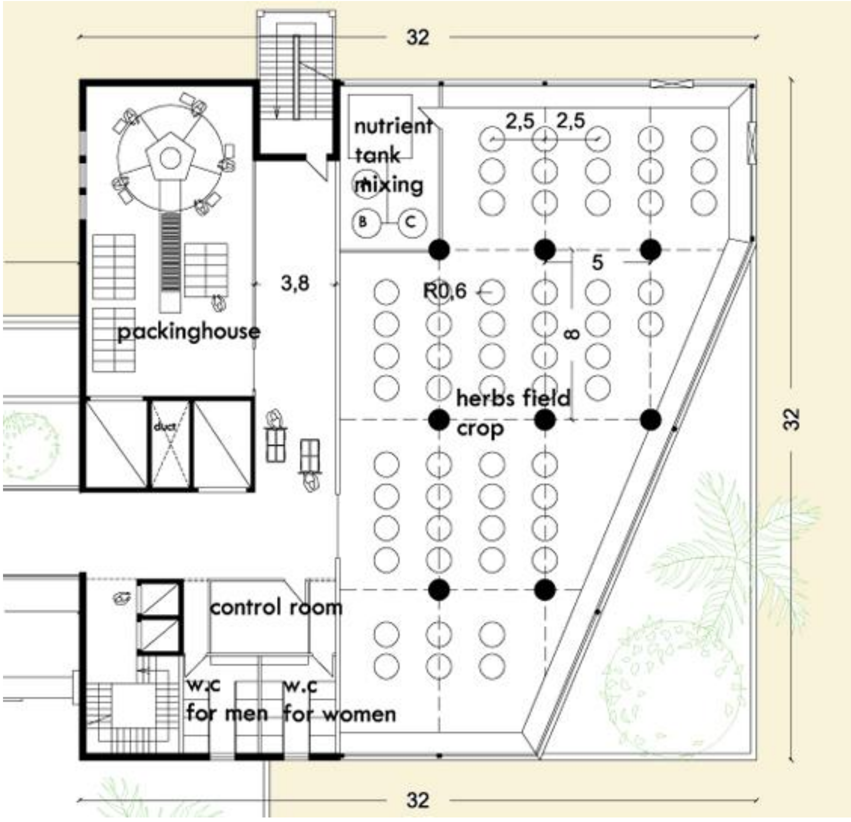


Figure 5.83 Typical floor plan showing herbs field arrangement

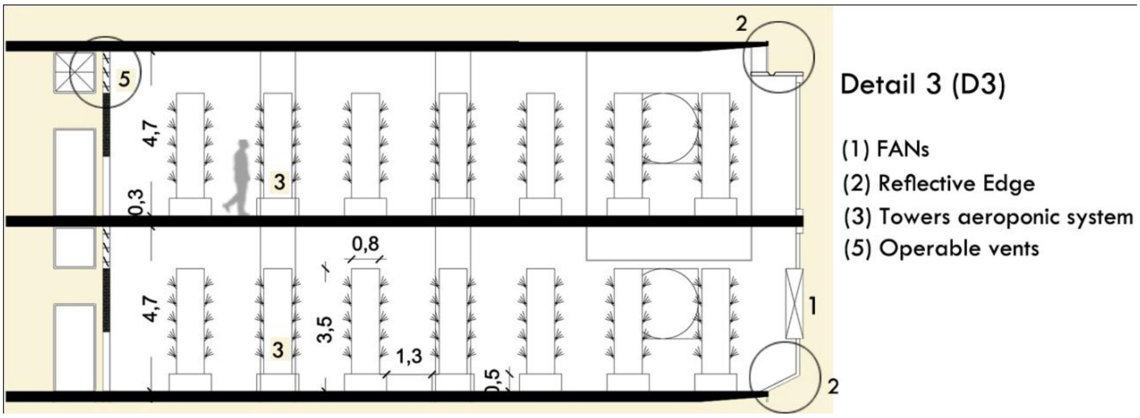


Figure 5.84 D3 showing aeroponic towers of herbs

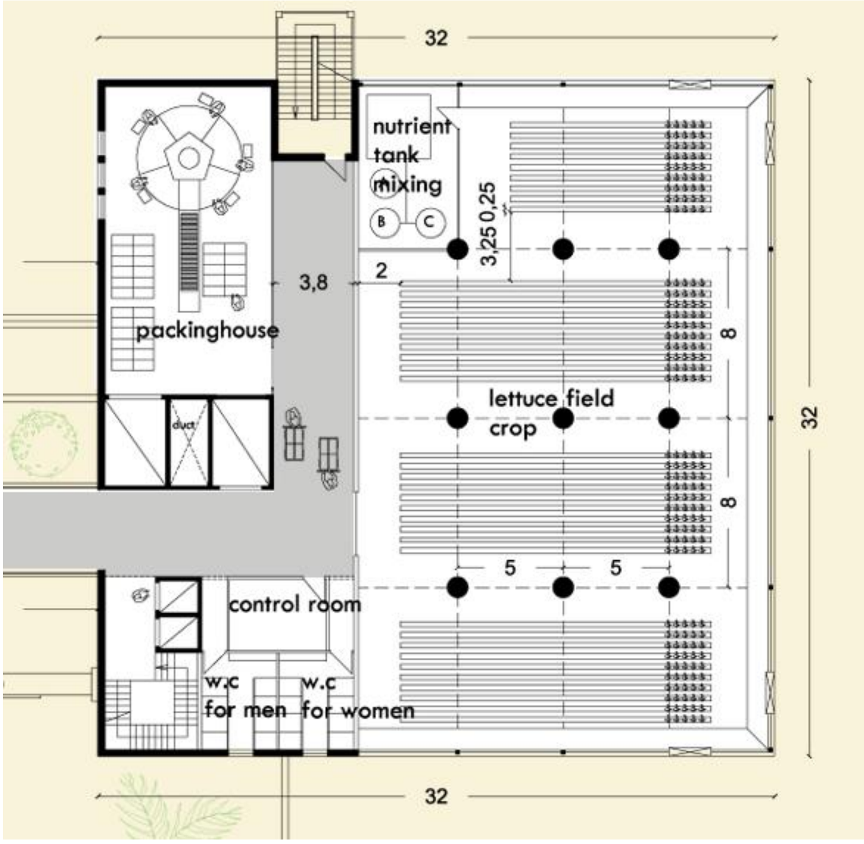


Figure 5.85 Typical floor plan showing chicory, lettuce, and spinach field arrangement

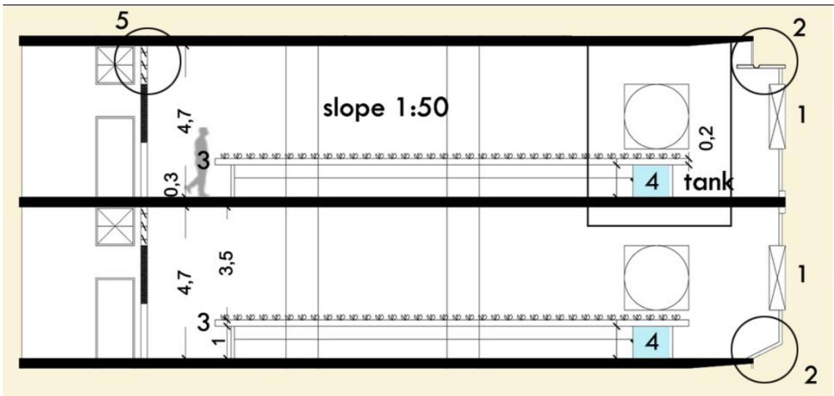


Figure 5.86 D4 showing NFT hydroponic benches

(E) Structure of the proposed vertical farm building:

The structure will be designed using concrete slabs and columns. Slab depth will be 30 cm, loaded on 1m diameter column; the module distance between columns is illustrated in the *figure 5.87.*

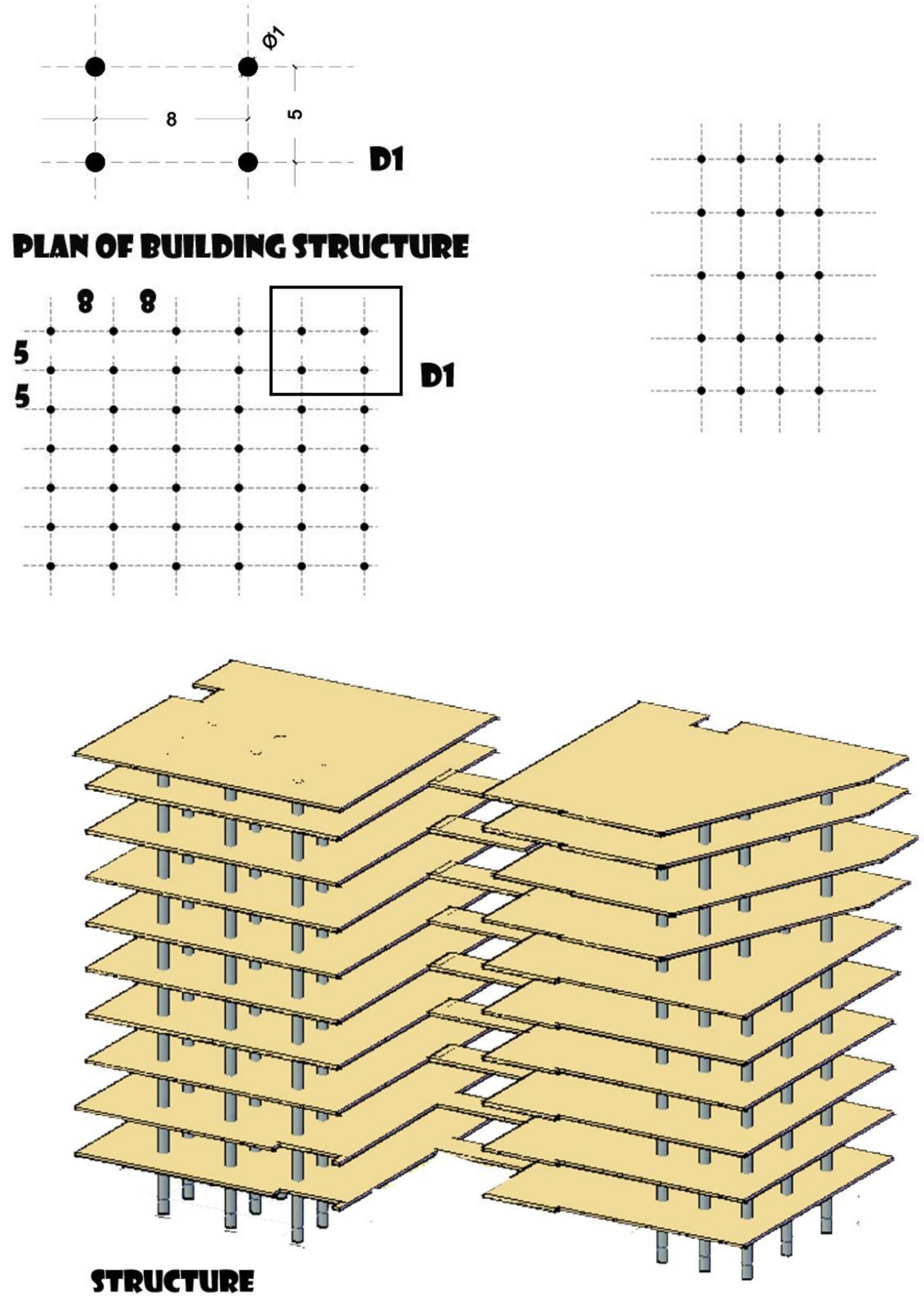


Figure 5.87 Plan and isometric of building showing the structural solution

(F) Ecological Green building solutions:

A strong emphasis is put into making the building sustainable through different strategies including, building natural ventilation/ day lighting, recycling of building water and waste, renewable energy, and building material constructions.

- **Building natural ventilation/day lighting:**

In terms of natural ventilation, the variation of temperatures can be customized for different crops through operable louvers to enter the fresh air through during the day, while throughout the night they are closed to keep the plants warm. The exhaust air is pumped out through fans in the opposite side.

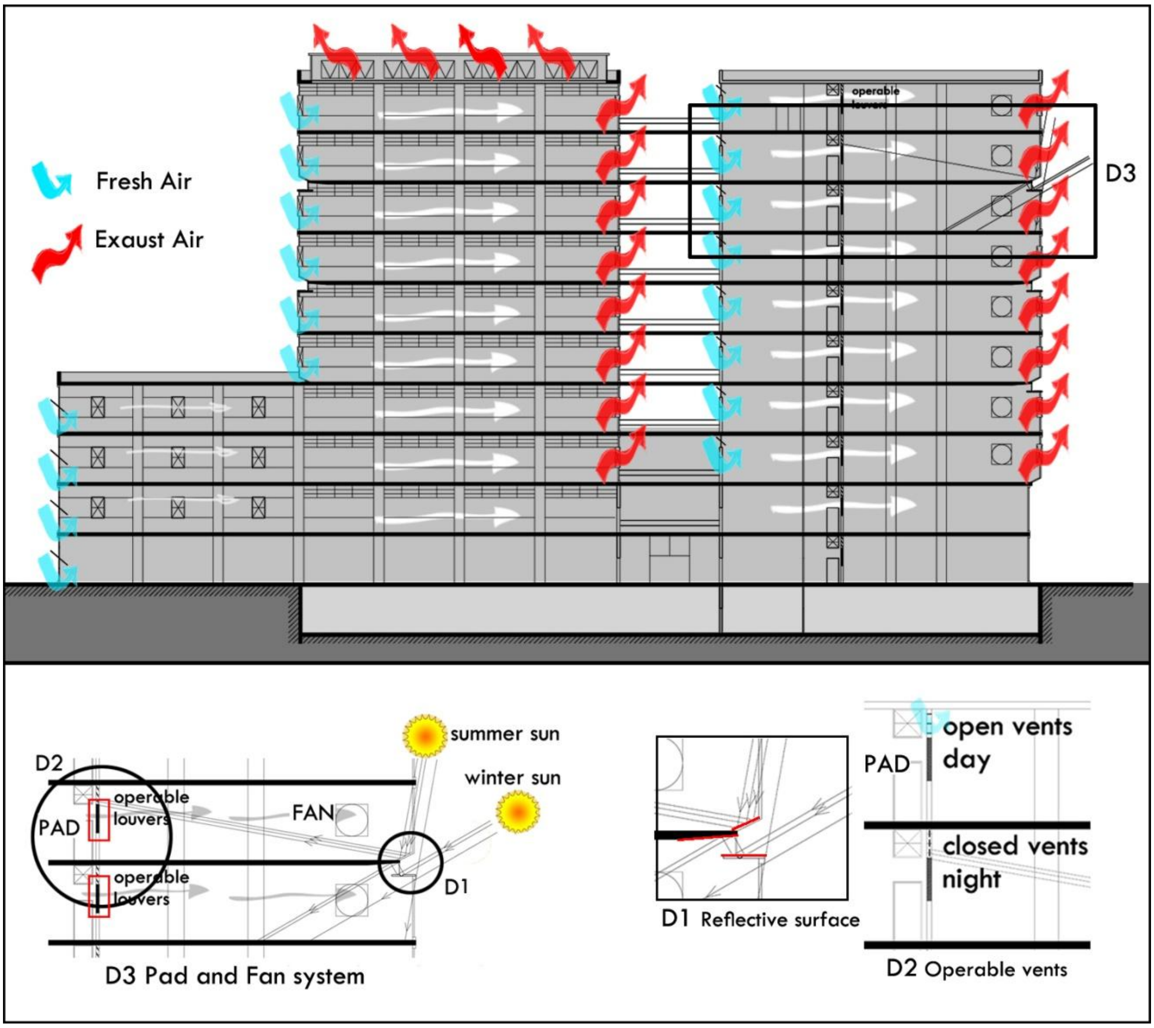


Figure 5.88 Section showing natural ventilation cycle and day lighting devices

As illustrated in the previous figure, the natural light that falls down on the reflected surfaces is diffused in the space to provide plants with light. The undesirable light in the summer is prevented through light shelves, as it works as both a shadow device, and a sunlight reflector.

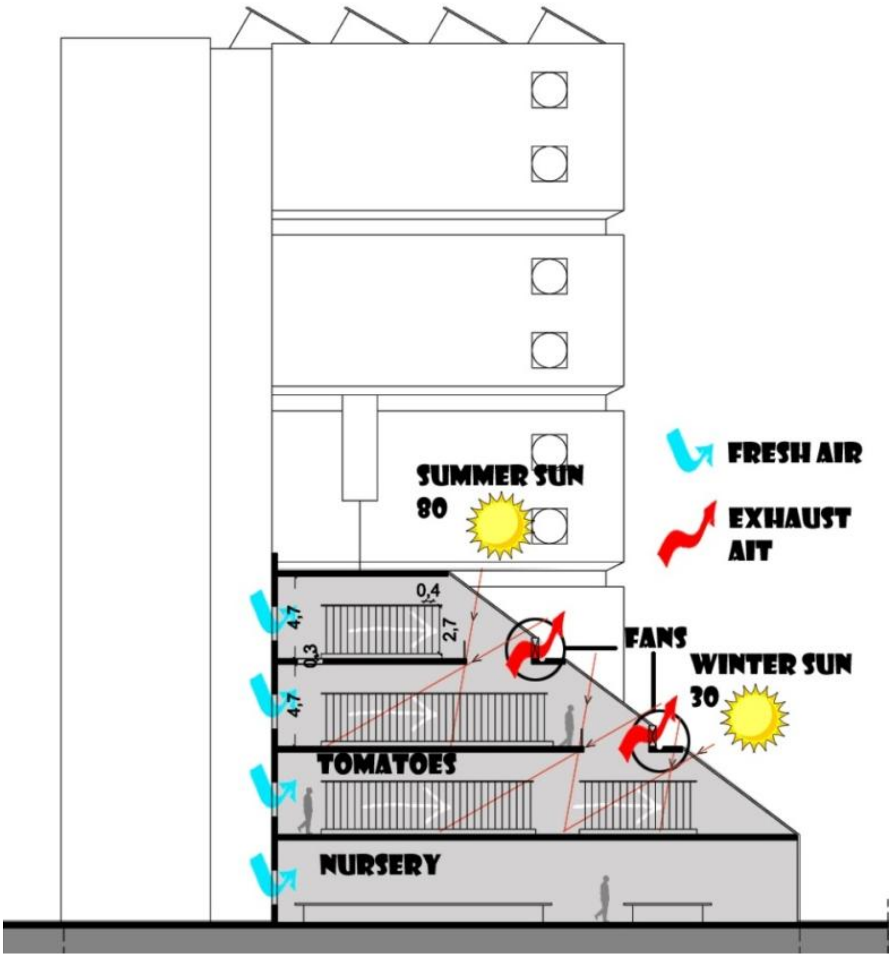


Figure 5.89 Section showing natural ventilation cycle in tomatoes field area

- **Water cycle:**

The water cycle is another interesting aspect, the declined surface even in the building roof or building outer surface *(see D1 in Figure 5.90),* is designed to harvest the rainwater through gutters, which accumulates in the rainwater harvest tank underground. After treatment the potable water is pumped up to the hydroponic system for plant irrigation. Black and grey water are recycled through the *living machine* to be used for toilets.

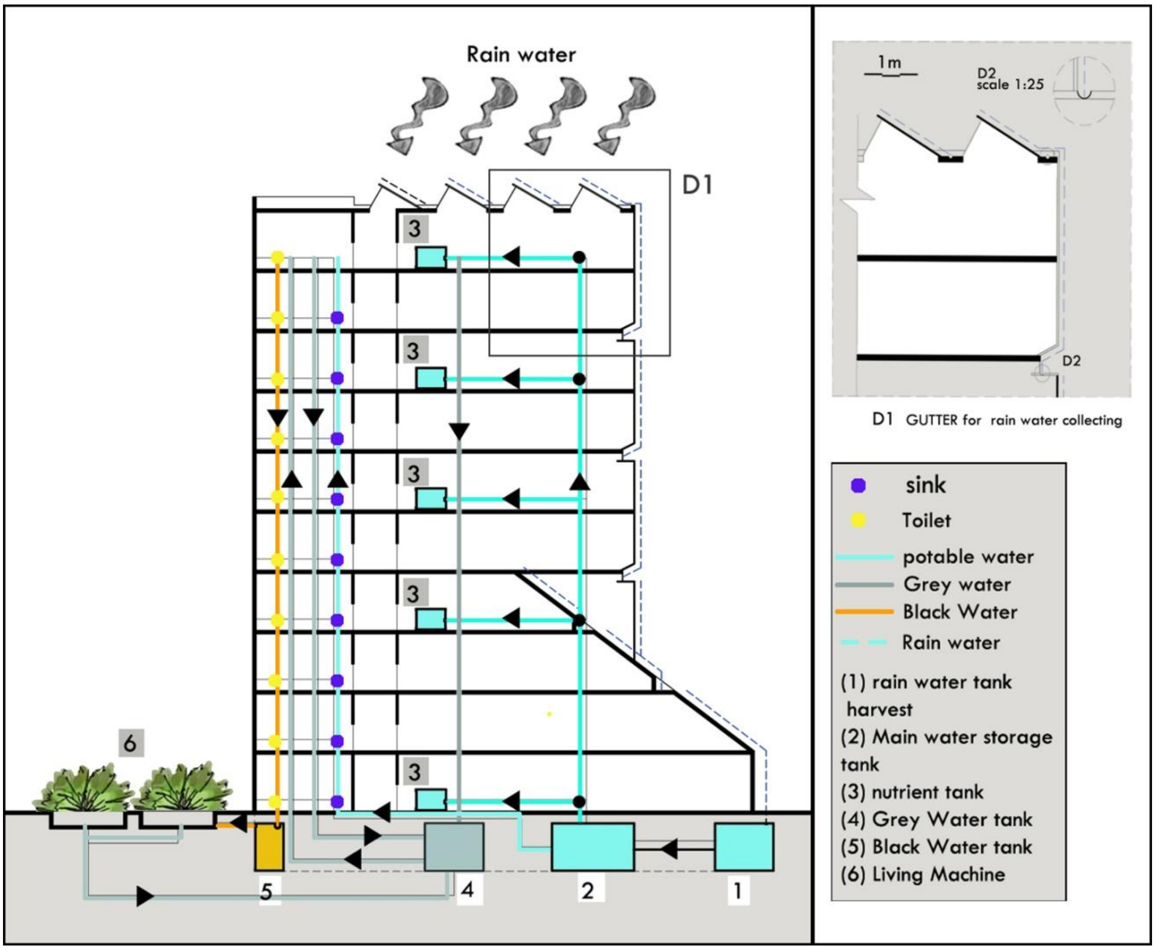


Figure 5.90 Section showing water cycle

- **Waste cycle:**

Waste cycle is also integrated in building design; the plant residue is collected from each floor through a vertical hole in the underground room. The biomass is then transferred into an adjacent digester to produce bio-gas for the building *(see Figure 5.91).*

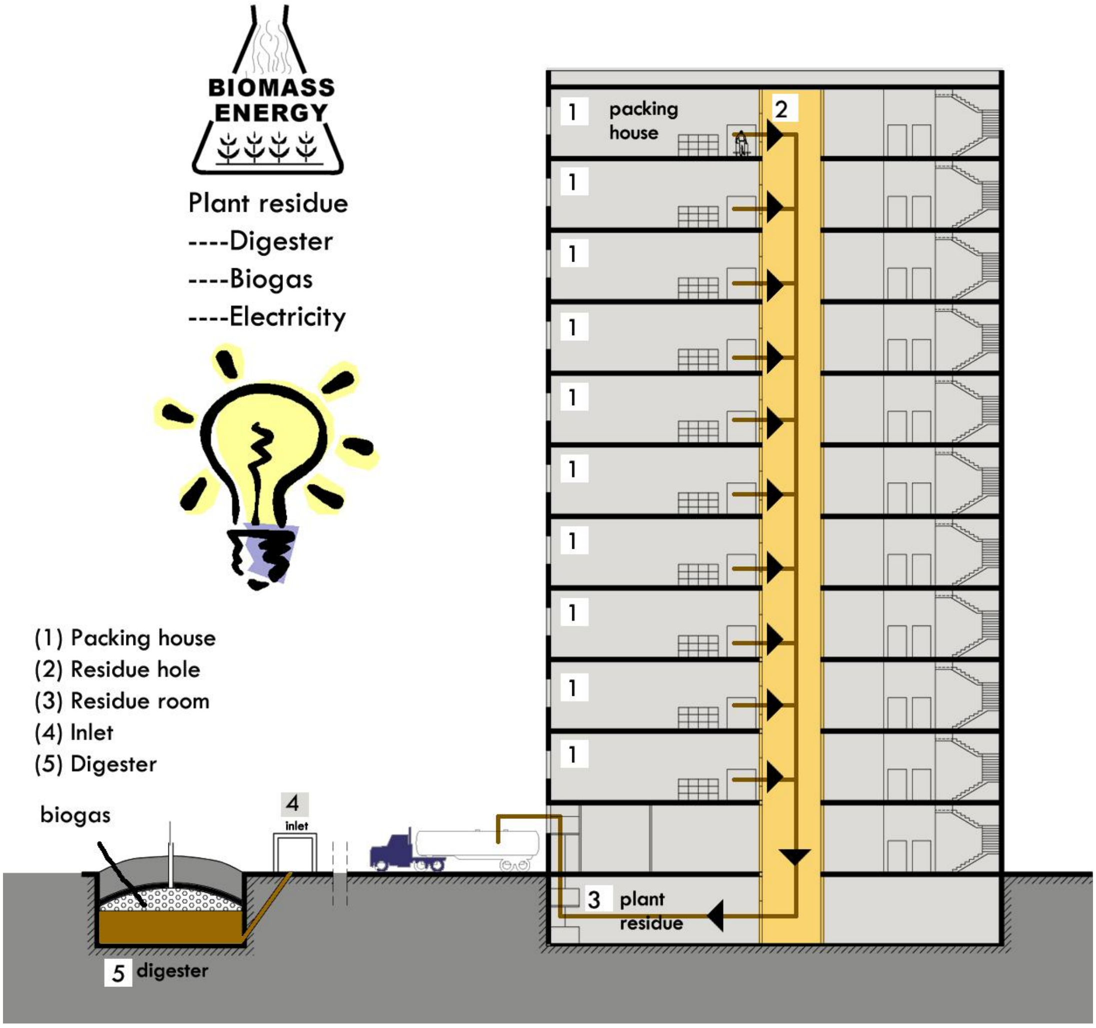


Figure 5.91 Section showing Waste cycle

- **Renewable Energy cycle (PV solar panels, wind turbines):**

In terms of energy, the building is designed to capture as much energy as possible from all elements. Horizontal wind turbines are located between the two vertical farm buildings, while the Mariah wind spire turbine (Vertical units) is installed in the rooftops. Each unit has annual energy production of 1800 KW at 11 mph, so three units will provide the building with 5400 KW\year *(see Figure 5.92).*

PV solar panels are located on the rooftop of vertical farm one facing the south direction, to capture maximum sun's rays; the solar panel energy is used to heat the water system that is used for heating the building in winter *(see Figure 5.93).*

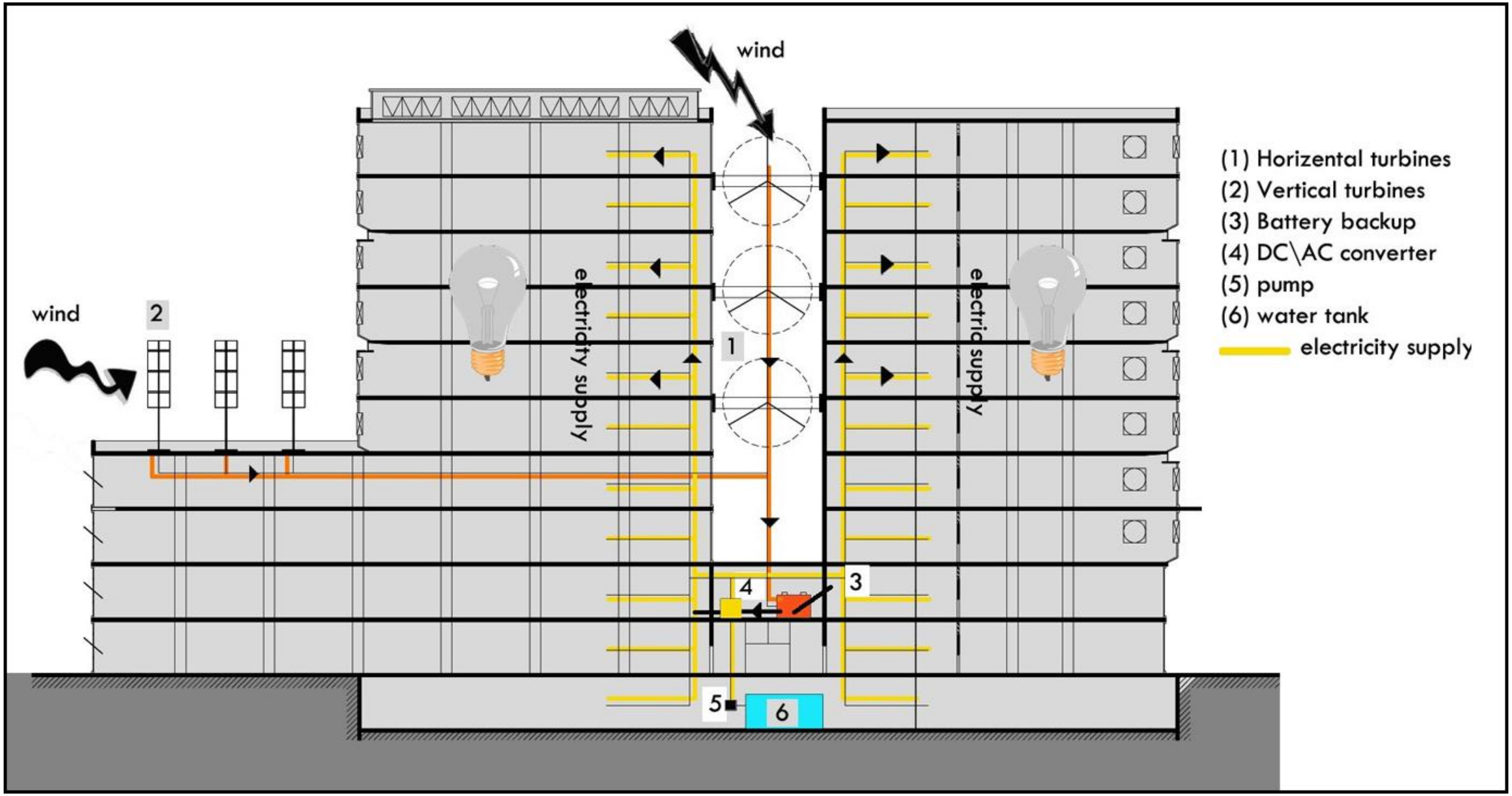


Figure 5.92 Section showing energy cycle\wind turbines

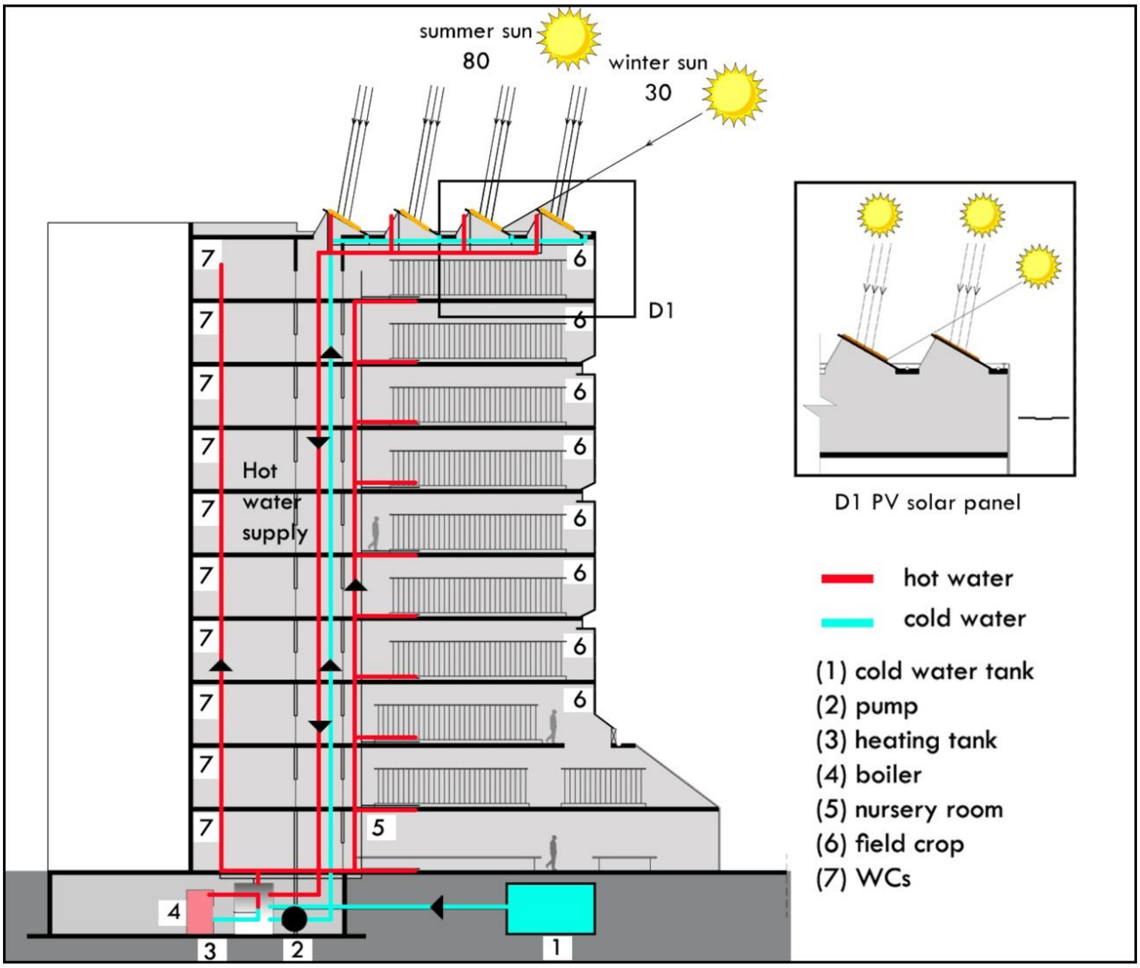


Figure 5.93 Section showing heating system by hot water solar panels

(G) Arrangement of vertical farm units:

Both vertical farm buildings have a separate functional system so that each one could operate individually. This makes it possible to have more than two buildings which will all integrate to produce more food to feed people.

Some solutions are designed by adding another building to an existing one without changing any of main building functions, some examples, are illustrated in *figure 5.94.*

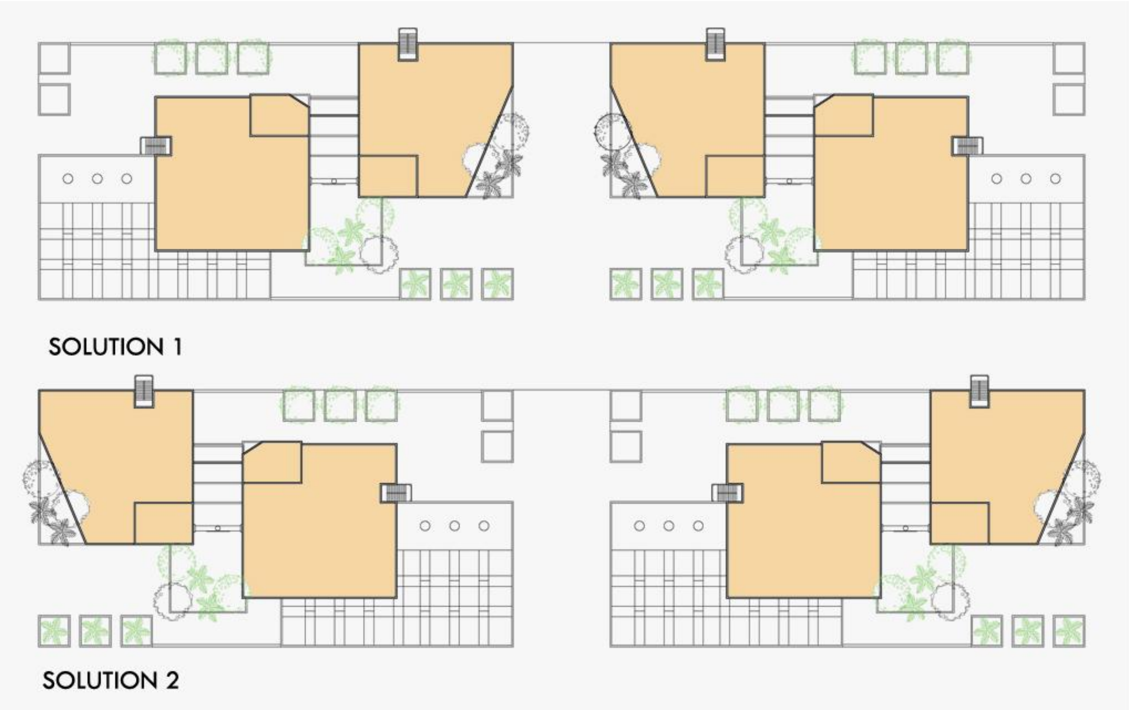


Figure 5.94 different solution of building blocks arrangement

This section has illustrated all the required architectural drawings and details to understand how vertical farm is functioning. But there is another important thing that will be introduced in the following pages; it is the final 3D real shots of vertical farm building, which are taken from different views, using 3D MAX software.

5.3.5.4. Final presentation:

- **Exterior perspective:**

Figure 5.95 Perspective showing south west view

Figure 5.96 Perspective showing north east view

Figure 5.97 Perspective showing north west view

Figure 5.98 Perspective showing south east view

- **Elevations:**

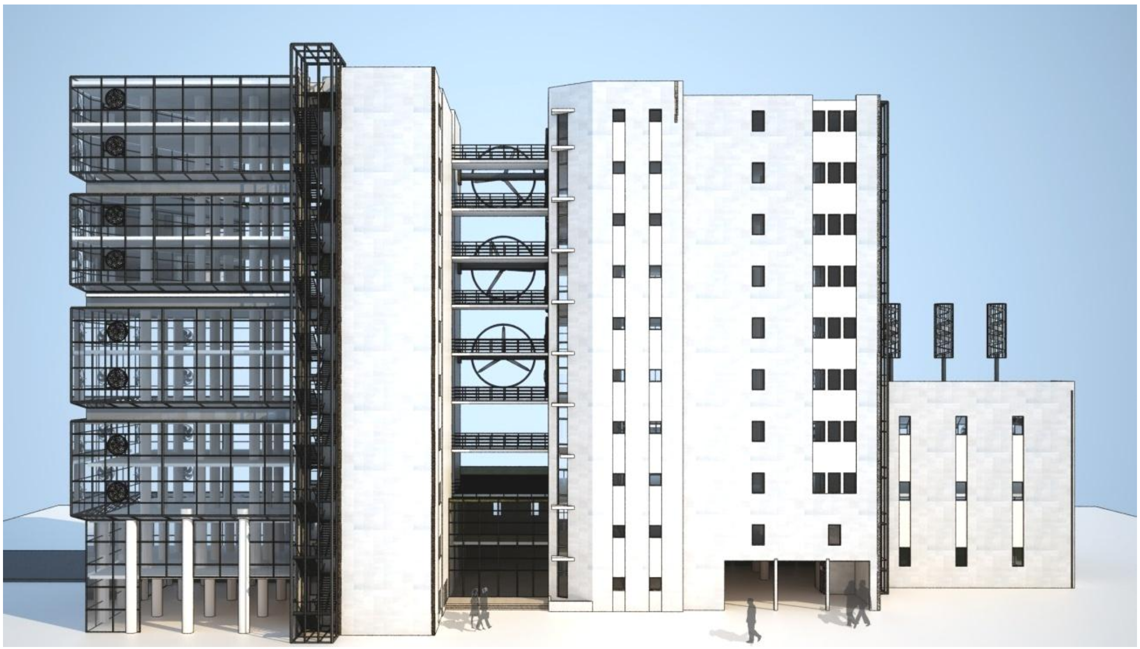


Figure 5.99 North Elevation

Figure 5.100 South Elevation

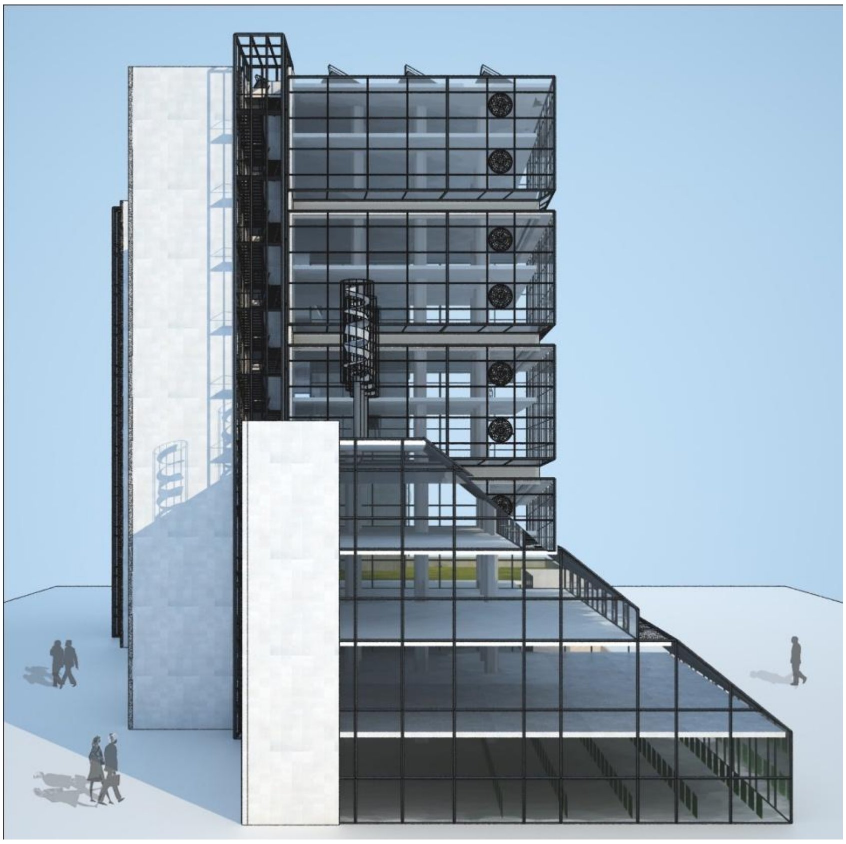


Figure 5.101 East Elevation

Figure 5.102 West Elevation

Figure 5.103 Top View

Figure 5.104 Bird-Eye perspective

5.4. Vertical farm project economic and environmental feasibility:

The vertical farm building feasibility should be evaluated in both economical and environmental feasibility. The following section will be the financial analysis of building construction, an analysis of production income, and an analysis of building energy demand and production, , and a comparison between traditional farming and the proposed vertical farm in terms of yield production, land area and water consumption.

5.4.1. Potential cost:

Anyone may wonder what vertical farm may cost. Since there aren't any comparable projects to consider when compiling an estimate, the engineers used the existing construction costs for skyscraper to produce viable cost estimation.

The research has another calculation method. By estimating the cost of expensive greenhouses with fully automatic control system per m^2***, which equals 100 JD\m^2*****, it could be easy to calculate the building construction cost by multiplying total area of building by JD 100. Adding the cost of living machine system, water pumps, hydroponic system, PV solar panels, and wind turbines *(see Table 5.25).*

Table 5.25 Construction cost calculations of the proposed model of vertical farm building.

Construction Element	Construction cost (JD)
Vertical farm building construction cost (20,100 m^2) (Heating, ventilation, cooling…)	**(total area * cost\m^2)** **20,100* JD 100= 2,010,000**
Living machine***	**100,000**
Water pumps**	**5250**
Hydroponic system	**5,000,000**
60 units of PV solar panels (20 W per unit), 130 JD\unit ****	**7,800**
Wind turbines	**5,450,000**
Offices and laboratory facilities	**3,000,000**
Total cost	**Approximately= 15,573,050 JD**

Source:

***** http://agritech.tnau.ac.in/horticulture/horti_Greenhouse%20cultivation.html, retrieved June 12, 2012

**http://www.treehugger.com/green-food/real-live-vertical-farm-built-in-south-korea-churning-out-lettuce.html, retrieved June 12, 2012

***http://www.nrmt.umd.edu/paperdesignandconstructionofafloatinglivingmachine.pdf, retrieved June 12, 2012

******** http://bc3.pnnl.gov/wiki/index.php/PV_Arrays_-_Solar_Panels**,** retrieved June 12, 2012

Total building cost for the proposed Vertical Farm is around JD 15 million.

Despite the high initial cost of vertical farm, economists estimates that in about seven years, the profit in fresh produce alone could pay for the initial investment. In addition, the energy and water that produced by vertical farm couldn't only sustain its own needs but also provide others such as local municipalities.

5.4.2. Production income of the proposed model of vertical farm building:

In the following *table 5.26* will be the total production income of each crop per harvest in JD.

Table 5.26 Total production income calculations per harvest of vertical farm crops:

Vegetables	Yield kg\m^2	Space area (m^2)	Total production\kg	JD\kg*	Total production income JD
Tomatoes	**68.02643**	**1800**	**122,400**	**.5**	**61,200**
Peppers	**59.66484**	**1200**	**71,590**	**.9**	**64,431**
Melon	**32.8**	**1200**	**39,360**	**.19**	**7,478.4**
Strawberries (2 layers)	**24.97232**	**1800**	**44,946**	**.82**	**36,855.72**
Lettuce	**75.19887**	**1200**	**90,000**	**.608**	**54,720**
Spinach	**11.03741**	**1200**	**13,200**	**1.1**	**14,520**
Chicory	**30.2**	**1200**	**36,000**	**1.2**	**43,200**
Mint	**3.2**	**600**	**1,920**	**1.6**	**3,072**
Parsley	**1.5**	**600**	**900**	**1.54**	**1,386**
Thyme	**2**	**600**	**1200**	**2.464**	**2,956.8**
Basil	**1.6**	**600**	**960**	**2.1**	**2,016**
	Total area	**12,000**			**319,034.4 JD**

Source: http://www.pcbs.gov.ps/Portals/_pcbs/Various_Data/vardata_2010_E_16.htm, (PCBS, 2012).

5.4.3. The proposed model of vertical farm building VS. traditional farming methods:

The proposed model of vertical farm building has many advantages and achieved many goals in comparison to the traditional way of farming, these are:

(A) Total crop production of proposed vertical farm equals several times the crop production using traditional farming:

The following *table 5.27* will illustrate the total production of each crop in the proposed vertical farm compared to the total production of traditional farming of the same area. We conclude that there are some crops such as Lettuce which have (45) times crops production compared to traditional farming production, while herbs especially parsley, has the minimum difference, as it has just (1.2) times that of traditional farming.

Table 5.27 Total production comparison between vertical farm project and traditional farming

	Proposed Vertical farm			Traditional farming		
Vegetables	Yield* kg\m^2	Space area (m^2)	**Total production**	Yield kg\m 2008	**Total production kg**	**times of production**
Tomatoes	68.02643	1800	**122,400**	7.5	**13,500**	**9 times**
Peppers	59.66484	1200	**71,590**	3.34	**4,008**	**17**
Melon	32.8	1200	**39,360**	2.78	**3336**	**12**
Strawberries (2 layers)	24.97232	1800	**44,946**	2.25	**4050**	**11**
Lettuce	75.19887	1200	**90,000**	1.65	**1980**	**45**
Spinach	11.03741	1200	**13,200**	1.6	**1920**	**7**
Chicory	30.2	1200	**36,000**	2	**2400**	**15**
Mint	3.2	600	**1,920**	.78	**468**	**4**
Parsley	1.5	600	**900**	1.22	**730**	**1.2**
Thyme	2	600	**1200**	1.3	**780**	**1.5**
Basil	1.6	600	**960**	-	**-**	-

Source: the author

(B) Only (3) dunums of land will be needed, while to produce the same quantity of crops using traditional farming method, we need another (150) dunums of land, required calculations will be illustrated in the following *table 5.28*:

Table 5.28 Total area comparison between vertical farm project and traditional farming

		Proposed vertical farm		Traditional farming	
Vegetables	**Yield* kg\m^2**	**Space area (m^2)**	**Total production kg**	**Yield kg\m 2008**	**Total required area**
Tomatoes	68.02643	1,800	**122,400**	7.5	**16,320**
Peppers	59.66484	1,200	**71,590**	3.34	**21,434**
Melon	32.8	1,200	**39,360**	2.78	**14,158**
Strawberries (2 layers)	24.97232	1,800	**44,946**	2.25	**19,976**
Lettuce	75.19887	1,200	**90,000**	1.65	**54,545**
Spinach	11.03741	1,200	**13,200**	1.6	**8,280**
Chicory	30.2	1,200	**36,000**	2	**18,000**
Mint	3.2	600	**1,920**	.78	**2,461**
Parsley	1.5	600	**900**	1.22	**737**
Thyme	2	600	**1200**	1.3	**923**
Basil	1.6	600	**960**	-	**-**
	Total area12,000m^2(12dunum) **Note: dunum=10^3 m^2**				**156,834(156 dunum)**

We conclude that vertical farms will solve for the lack of agricultural land, and the access to food production will be possible, as vertical farm will be in the middle of urban cities close to the local markets, to provide people with fresh food.

(C) A saving of 70% of the water used in traditional farming irrigation method:

The proposed vertical farm will harvest about 200,200 gallons through rainwater collecting system, while 74,186 gallons of water will be used to irrigate the plants. The grey water is recycled and used in toilets of the building. The following *tables (5.29, 5.30)* will illustrate the difference of water demand between the proposed vertical farm water needs and traditional farming consumption.

Table 5.29 Total water demand by the proposed vertical farm building

Plant	Liters of water L\m^2\day	Total area	Total demand (L)
Tomatoes	10	1600*3= 4800	48000 (48 m^3)
Peppers (bedding plant)	20	30*20*2= 1200	24000 (24 m^3)
Melon	20	30*20*2= 1200	24000 (24 m^3)
Strawberries (bench)	15	30*20*2= 1200	18000 (18 m^3)
Lettuce	15	30*20*2= 1200	18000 (18 m^3)
Spinach	15	30*20*2= 1200	18000 (18 m^3)
Chicory	15	30*20*2= 1200	18000 (18 m^3)
Herbs (pot)	20	4*20*30= 2400	48000 (48m^3)
Storage tank capacity	**234,000 L = 234 m^3= 61822 gallon\day**		

Table 5.30 Total water demand by traditional farming methods

Plant	**Liters of water L\m^2**	**Total area**	**Total demand (L)**
Tomatoes	15	1600*3= 4800	72,000
Peppers	28	30*20*2= 1200	33,600
Melon	28	30*20*2= 1200	33,600
Strawberries	20	30*20*2= 1200	24,000
Lettuce	20	30*20*2= 1200	24,000
Spinach	20	30*20*2= 1200	24,000
Chicory	20	30*20*2= 1200	24,000
Herbs	28	4*20*30= 2400	67,200
Storage tank capacity			**324,400 = 324.4 m^3**

(D) Plant waste would be used biogas to supply the project with a considerable share of its power needs.

(E) The proposed vertical farm will have minimum CO2 emissions compared to traditional farming methods.

The proposed vertical farm is designed to be a self-reliant energy system, as the wind turbines (vertical wind turbines 300 KW, horizontal wind turbines), and PV solar panels (430 KW) provide the building with energy. The renewable energy has zero net CO2 emissions.

CHAPTER SIX

CONCLUSION AND GENERAL GUIDELINES

6.1. Conclusions:

- Based on population, plant production, and city planning requirement, the space required for the Vertical Farm may be modified.
- The proposed vertical farm, previously outlined, presents a self- sustainable model within the urban setting that meets the need of (10,000) people. This means that we need another (30) vertical farm buildings to feed a city such as Nablus, which has more than (350,000) inhabitants.
- The proposed Vertical Farm would consist of (10) stories, with (12,000) m^2 total area and (2,700) m^2 of ground floor level, depending on the previously outlined requirements, such as, yield production of each crop, sunlight requirement, hydroponic and irrigation system.
- The Vertical Farm is an urban agricultural design that will guide metropolitan areas into sustainable future. In looking towards managing future increased populations, concept such as the Vertical Farm must be embraced, and made a reality.
- The proposed model of Vertical Farm building will achieve the following main goals:

a) Total crop production several times that production using traditional farming methods.

b) Only (3) dunums of land will be needed, while to produce the same quantity of crops using traditional farming method, we would need 150 dunums of land.

c) A saving of 70% of the water used in traditional farming irrigation method.

d) Plant waste would be used biogas to supply the project with a considerable share of its power needs.

e) Having minimum CO_2 emissions compared to traditional farming methods.

- ***Total building cost for the proposed Vertical Farm is around JD 15 million.*** Despite the high initial cost of vertical farm, economists estimates that in about seven years, the profit in fresh produce alone could pay for the initial investment. In addition, the energy and water that produced by vertical farm couldn't only sustain its own needs but also provide others such as local municipalities.

6.2. General guidelines of vertical farm design and site locations:

6.2.1. Vertical farm design guidelines:

There are four major themes that designers and engineers must include in any version of a vertical farm:

- Capture sunlight and disperse it evenly among the crops.
- Capture passive energy for supplying a reliable source of electricity.
- Maximize the amount of space devoted to growing crops.
- Employ a good barrier design for plant production.

6.2.2. Criteria of site potential locations

When considering a site location, the designer should try to meet as many of the following requirements as possible in order to maximize building efficiency and success.

- A region which has a maximum amount of sunlight.
- Full east, south, and west exposure to sunlight.
- Flat area or one that can be easily leveled to have maximum wind power.

- Good quality water capable of supplying at least one-half gallon of water per plant per day.
- Good internal drainage system.
- Close to urban centers which have a good labor force supply.
- Close to universities and educational institutions for easy access to experts.
- Access to main roads and access points outside the country such as airports and ports.
- Avoiding areas having excessively strong winds.

RECOMMENDATIONS

- To construct and manage a vertical farm would require the cooperation and support of governments, departments, and employees including: city planning department, economists, civil and environmental engineers, energy management specialists, and agricultural engineers.
- Extensive cooperation among industrial and government partners would be required to establish vertical farming on a significant scale in urban areas. Land would need to be identified, rezoned, and developed for vertical farming.
- Vertical farm design process could be the outline of an academic course in our universities for both architects and agricultural students.
- Making all the required standards and dimensions of plant design requirement, available and accessible to designers and researchers to promote further research, and enhance the vertical farm applicability.
- Vertical farm information packages should be distributed and presentations should be made to relevant agencies to lay the groundwork for future plans.
- Technology is improving rapidly in agriculture, so it is necessary to review innovative technologies, prior to the vertical farm implementation, in order to allow the incorporation of improved technologies.

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Appendixes

Appendix 1: Palestine background: population growth, macro-climate, zones of climate, potential for renewable energy

1- Palestine future population growth

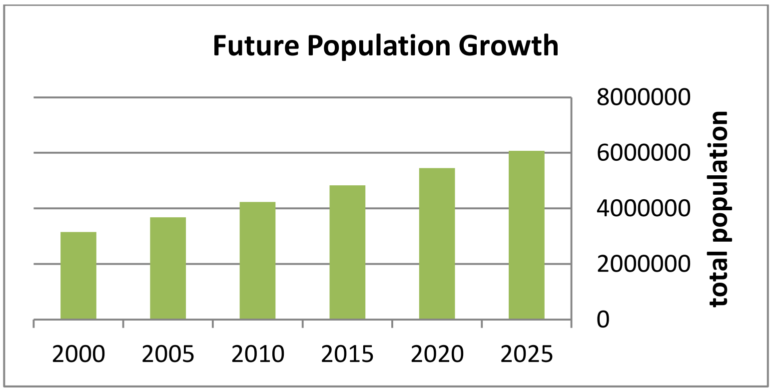


Figure 1. population growth 2000-2025
source: (Attane and Courbage, 2004)

2- Climate of Palestine

The climate of the Palestinian Territories is influenced by the Mediterranean climate where long, hot, dry summer and short, cool, rainy winter climate conditions prevail.

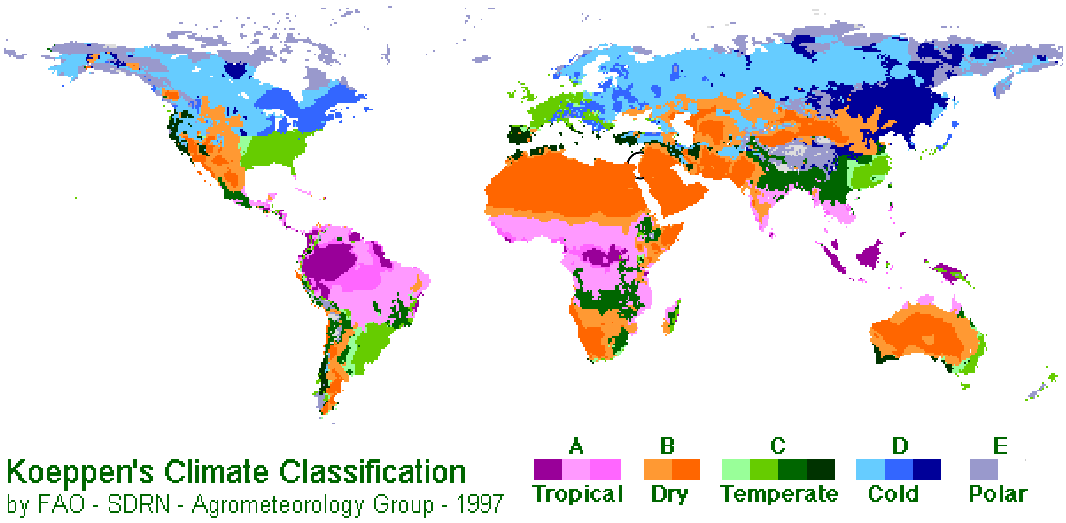


Figure 2. Palestine macro- climates
Source: http://www.blueplanetbiomes.org, retrieved April 2, 2012.

3- Climatic zones

Climate of west bank area is classified into five climatic zones, which represent the climatic characteristic of the four distinctive climatic and topographic regions of the west bank (Hadid M., 2002).

Figure 3. Climate zoning in west bank, **source:** http://www.arij.org/publications/papers/333-climatic-zoning.html, retrieved March 30, 2012.

Climatic zones of Palestinian territories

Climatic zone	Location	Annual mean Temperature	Average Wind speed	sunshine	Annual rainfall average	annual average of humidity
Zone 1 Steppe climate arid regions	Located in the Eastern slope, the dead sea area, and part of the Jordan Valley area.	15C° in January (coldest month), 30C°in August (hottest month).	3.4 km/h	12 hr/day in July and 5 hr/day in January	125 mm	--
Zone 2 Steppe climate arid region	The northern part of Jordan Valley and the Southern mountains areas.	13C° in January (coldest month), 27C°in August (hottest month).	5 km/h	8.5 hr/day	239 mm	--
Zone 3 Mediterranean climate	Started from Hebron Mountain in the South and ends in Jenin	12C° in January (coldest month), 26 C°in August (hottest month).	4.7 km/h and	8.5 hr/day	316 mm	--
Zone 4 Mediterranean climate	A narrow strip to the west of Zone 3 and some island in the northern part of West bank	11C° in January (coldest month), 25 C°in August (hottest month).	---	---	715 mm	60 %
Zone 5 Mediterranean climate		12C° in January (coldest month), 25 C°in August (hottest month)	---	---	534 mm	62 %.

Source: http://www.arij.org/publications/papers/333-climatic-zoning.html, retrieved March 30, 2012.

4- Water situation in Palestine territories

In the Palestinian Territory, around 220 liters of water are available daily\capita, while each one needs nine times this amount of water in order to produce their daily food (PCBS, 2012).

Future agricultural water need:

Future water needs for the agricultural sector however were estimated based on the average crop need for water. Total future water needs by the three sectors for (2010, 2015 and 2020) are shown in following Table 1 (Jayyousi and Srouji, 2009).

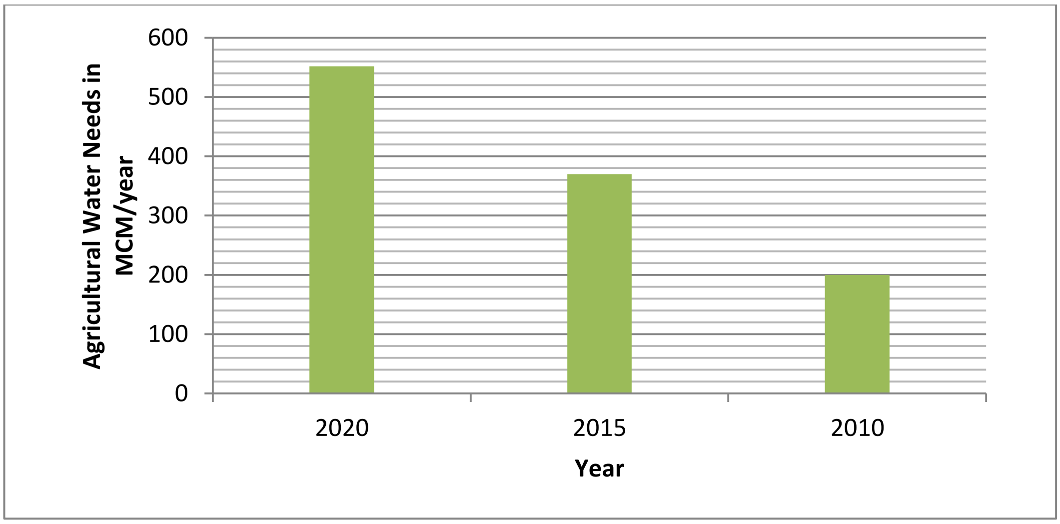


Figure 4. Projected Agricultural Water Needs in MCM/years, **source: (**PCBS, 2011)

5- Renewable energy

The Palestinian Territories relies on Israel for 100% of its fossil fuel imports and for 87% of its electricity imports. Total energy consumption in the Palestinian Territories is the lowest in the region and costs more than anywhere else in the Middle East.

It is shown that the main renewable energy sources in the Palestinian Territories are solar, wind and biomass. Using the available renewable energy sources in the

Palestinian Territories may significantly decrease the energy reliance on neighboring countries and improve the Palestinian population's access to energy. It is estimated that solar sources have the potential to account for 13% of electricity demand and wind energy for 6.6%. The conversion of animal waste into biogas has the potential to meet the needs of 20% of the rural population. The conversion of unused agricultural residue into biodiesel could replace 5% of the imported diesel (Abu Hamed et al., 2011).

Appendix 2: main crops in the Palestinian territory, consumption, production, yield 2010

vegetables	Consumption (kg)	total cons.\month	cons. Ton\year	production ton	Yield (ton\dunum)	area 2010	production ton 2010
Cucumber	6.897	3041072	40226.5	208,182	6.435699	18330.13	117967.2
marrow	3.194	1408320	18628.89	48,506	1.720986	17530.55	30169.84
Tomatoes	12.81	5649154	74725.52	207,559	8.328679	14202.05	118284.3
Eggplant	3.197	1409643	18646.38	59,655	5.093059	8981.25	45742.04
Maize	0.499	220022	2910.399	12,481	1.319066	5444.77	7182.01
Cauliflower	3.479	1533984	20291.14	24,840	2.859116	5887.23	16832.27
white cabbage	1.23	542340	7173.93	22,376	3.520453	2835.62	9982.667
snake cucumber		0	0	3,140	0.508832	3698.23	1881.776
okra	0.239	105382	1393.959	2,411	0.42522	4337.59	1844.432
Jew's mallow	1.365	601865	7961.312	12,434	2.304299	2458.46	5665.028
broad bean	0.297	130955	1732.242	3,917	0.772889	3,371.82	2606.042
green pepper	1.136	500893	6625.678	16,802	3.711509	2,993.90	11111.89
kidney bean green	--	0	0	5,569	1.289419	2,836.12	3656.947
peas	0.074	32628.6	431.6023	2,208	0.521862	3,331.85	1738.767
chick peas	--	0	0	3,265	0.835252	743.73	621.202
water melon	--	0	0	17,282	4.881921	1230.68	6008.082
spinach	0.572	252210	3336.169	4,297	1.794904	1255.23	2253.017
onion green	0.077	33951.4	449.0997	2,805	1.275	2895.26	3691.457

pumpkin	0.054	23810	314.953	1,355	0.906961	711.01	644.8585
parsley	0.173	76280.3	1009.016	1,916	1.356941	719.62	976.4815
carrot	1.439	634494	8392.91	3,421	2.491624	841.96	2097.848
green cowpea	0.051	22487.3	297.4556	797	0.592565	625.37	370.5724
strawberry	--	0	0	3,150	2.5	1,062.51	2656.275
muskmelon	--	0	0	3,733	3.103076	1219.87	3785.349
radish	0.19	83776.1	1108.168	2,168	1.908451	375.61	716.8332
turnip	0.164	72312	956.524	2,748	2.993464	509.55	1525.32
lettuce	0.227	100090	1323.9	1,705	1.857298	296.25	550.224
fennel	--	0	0	2,565	3.659058	237.21	867.9653
gourd	0.035	15432.4	204.1362	717	1.162075	484.16	562.63
dry garlic	--	0	0	1,371	0.871583	145.1	126.4667
green thyme	0.226	99649.5	1318.137	3,227	1.459521	2,099.20	3063.826
green sage	0.03	13227.8	174.9739	203	1.180233	174.71	206.1984
ment	0.069	30423.9	402.44	108	0.870968	119.88	104.4116
afokado	0.761	335545	4438.504	344	2.646154	197.76	523.3034
potato	--	--	--	69,180	3.266752	13,814.05	45127.07

Appendix 3: Soilless Agricultural System (Hydroponic, Aeroponic, Aquaponic)

Vertical farm crops can be grown using *hydroponics*, where plants grow in water or in a medium with nutrients delivered directly to their roots, *aeroponics*, which uses a mist to deliver nutrients to plant roots, and *aquaponic*, when fish are raised concurrently and their waste is used as nutrients for crops (http://blogs.ei.columbia.edu, retrieved May 13, 2012).

- **Main Types of Hydroponic Systems:**

There are six main hydroponics systems which are used indoors to cultivate crops, as illustrated below:

1. Nutrient Film Technique(NFT):

In this method, the plants are suspended above a constantly flowing stream of nutrient solution, which is (1-3) mm deep; the plant is usually in a rock wool cube within a mesh container with the roots dangling down into the solution.

Waste water must be filtered of root debris before it is returned to the holding tank; the system also uses a pump so it is reliant on a constant source of electricity (Venter, 2010, p.p.139).

2. Wick System:

It is the simplest type of the hydroponic six systems, because there are no moving parts (drippers, pumps), which makes it as "a passive system". The nutrient solution is drawn up in the growing medium from a reservoir below the pot via a form of wick, it is not suitable for large plants as more nutrient drawn than the wick can supply, thus drying out the plant (Venter, 2010, p.p.139).

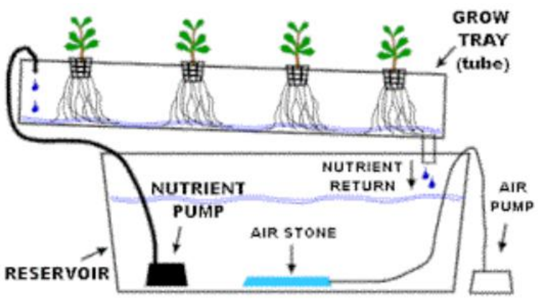


Figure 5. Nutrient Film Technique,
Source:
http://hydroponicshabitat.com/hydroponic-systems, retrieved June 2, 2012

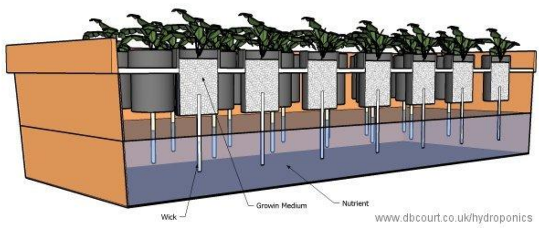


Figure 6. Wick System,
Source: http://www.dbcourt.co.uk/, retrieved June 2, 2012

3. Water Culture:

It is also a very simple hydroponic systems, the plant is suspend in the nutrient solution, using floating polystyrene\Styrofoam platform. This system is scalable and has been used to produce very large scale leaf crops such as lettuce or other small fast growing crops (Venter, 2010, p.p.140).

4. Ebb and Flow System (Flood and Drain):

It is a non passive system, as it requires a pump of some type; the plant is suspended in a vessel, where the roots are subjected to a flood of water covered them, then the water is allowed to drain away, thus oxygenating the roots. Large plants such as rhubarb, tomatoes, and potatoes grow well in this type except lettuce (Venter, 2010, p.p.139).

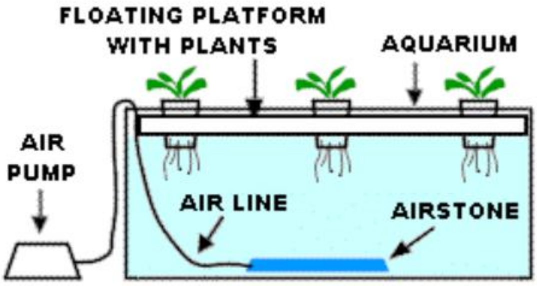


Figure 7. Water Culture

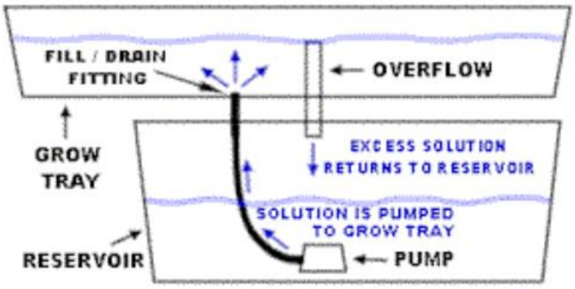


Figure 8. Ebb and Flow system

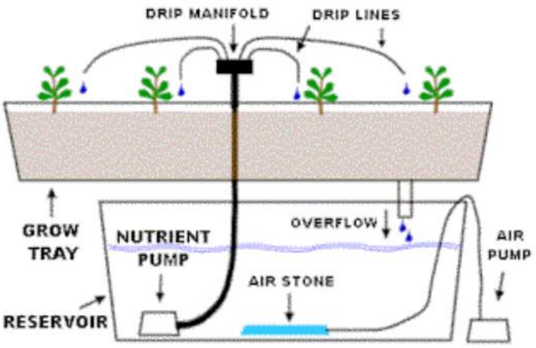
Source: http://hydroponicshabitat.com/hydroponic-systems, retrieved June 2, 2012

5. Drip feed system:

It is probably the most widely used type; the plant is grown in a pot containing a free draining medium such as grow rocks or perlite. The nutrient is dripped into the pot, and then caught at the bottom and returned to a tank (Venter, 2010, p.p.140).

6. Aeroponic system:

Aeroponics is in some ways the ideal concept of a hydroponic system, but in actual fact it proves to be flawed. The principle is simple; the plant is suspended above a vessel with the roots hanging down in the chamber below to be misted with nutrients. It is reliable on power supply, as it is a constant misting of nutrients (Venter, 2010, p.p.141).



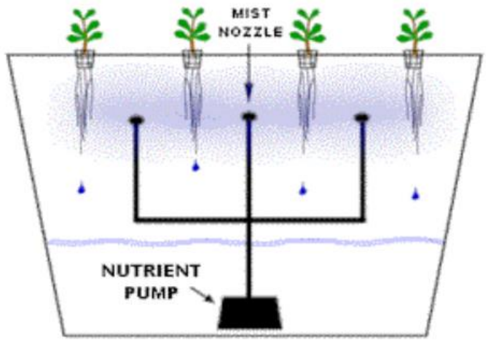


Figure 9. Drip Feed System **Figure 10.** Aeroponic System
Source: http://hydroponicshabitat.com/hydroponic-systems, retrieved June 2, 2012

- **Aquaponic system:**

It is a sustainable food production system that combines the traditional aquaculture with hydroponics. In the aquaculture, waste water which flows from plant accumulates in the water, increasing toxicity for the fish, this water is led to a hydroponic system where the byproduct from the aquaculture are filtered out by the plants as vital nutrients, after which the cleaned water is re-circulated back to the animals (Wikipedia, April, 2012).

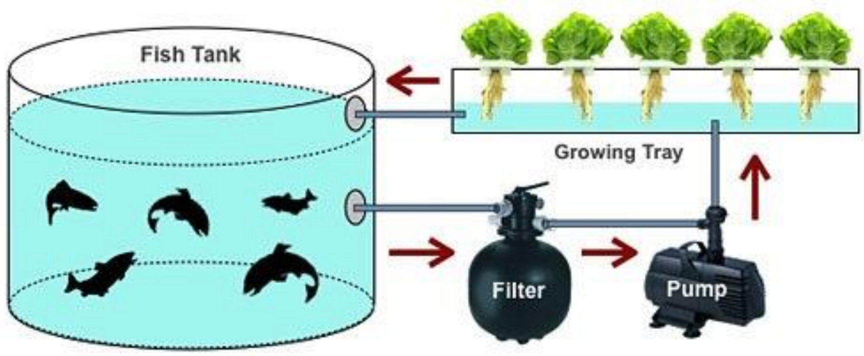


Figure 11. Aquaponic System
source: http://2.bp.blogspot.com, retrieved June 2, 2012

- **Nutrient Solution: Closed and Open system**

1. Open Nutrition System:

In open nutrition system, the drained nutrient solution from plant root zone is thrown out of the system. The main criterion is determination of irrigation water volume together with plant nutrient concentrations.

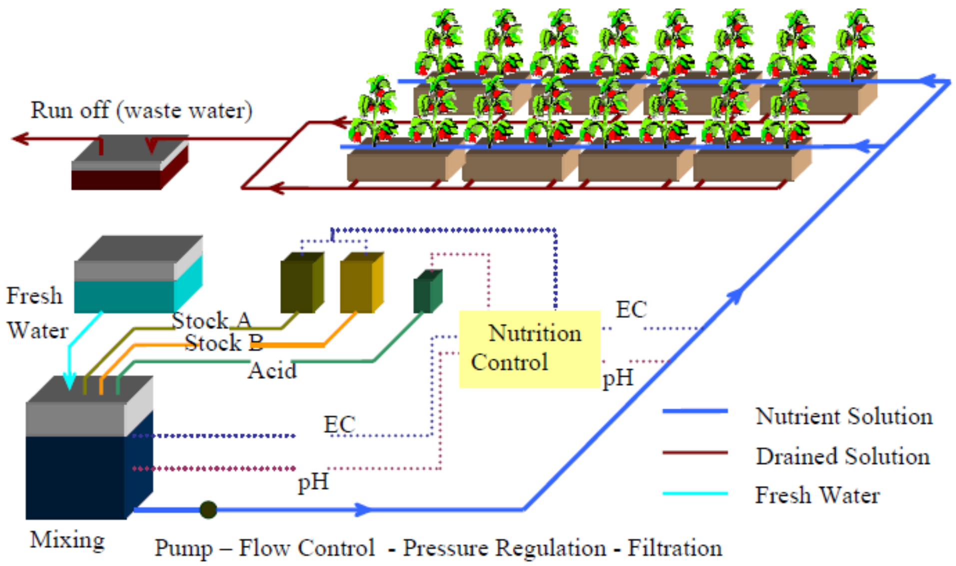


Figure 12. A scheme of a simple open soilless system

2. Closed Nutrition System:

Closed system is different from open system in terms of nutrient management and control, although same EC and PH could be used for both, more precise and frequent nutrient solution control and technical knowledge is needed for operation of the system.

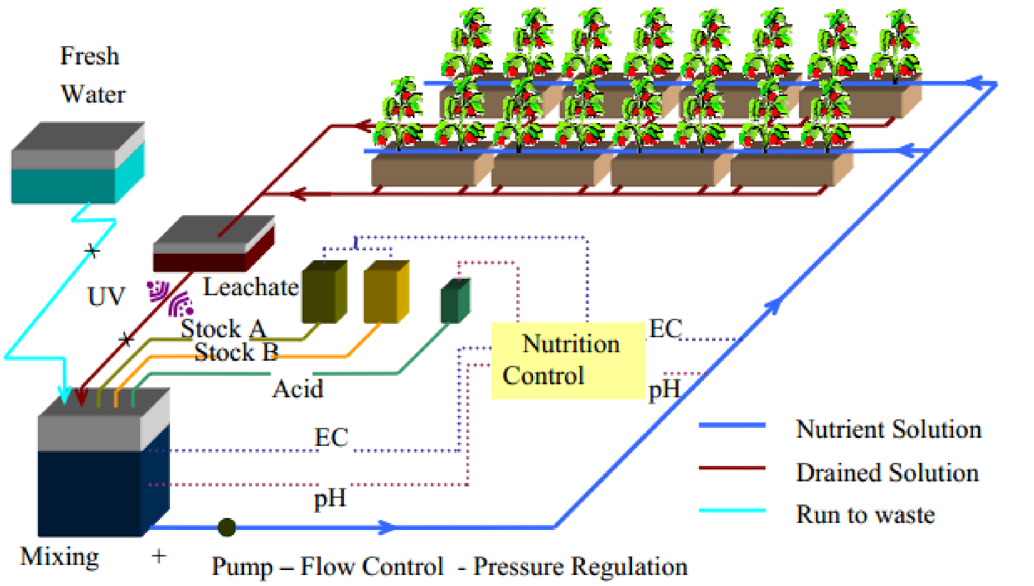


Figure 13. A scheme of a simple soilless closed system
source: (Ecoponics project, 2006)

Practice of Soilless Agriculture in Palestine and Jordan:

- **Greenhouse Project in Jordan University of Science and Technology (JUST) in Irbid in Jordan:**

It is a small greenhouse project, under the supervision of Dr. Gazi Al-Karaki, used hydroponic systems to cultivate a variety of vegetables crops such as strawberries, cherry tomatoes, green peppers, and some kinds of cut flowers.

Different types of hydroponic system are used, such as, A frame NFT hydroponic system for strawberries, bed drip irrigation system for tomatoes, and hydro-stacker drip irrigation system for some kinds of cut flower. Volcanic Tuff is the medium used in hydroponic system, as it is non-expensive.

Figure 14. A frame NFT hydroponic system of Strawberries in JUST

Figure 15. Bed drip irrigation hydroponic system of cherry tomatoes in JUST

Source: the author.

- **Nimer Farms project in Madaba in Jordan:**

It is one of the largest greenhouse strawberries production, used NFT benches in 3 layers, but the lowest layer has the minimum production as it received the minimum sun light than the upper layers.

Source: (Dr. Muein Qaryouti, Director of Horticultural Research)

Figure 16. NFT hydroponic benches of strawberries in Nimer farms

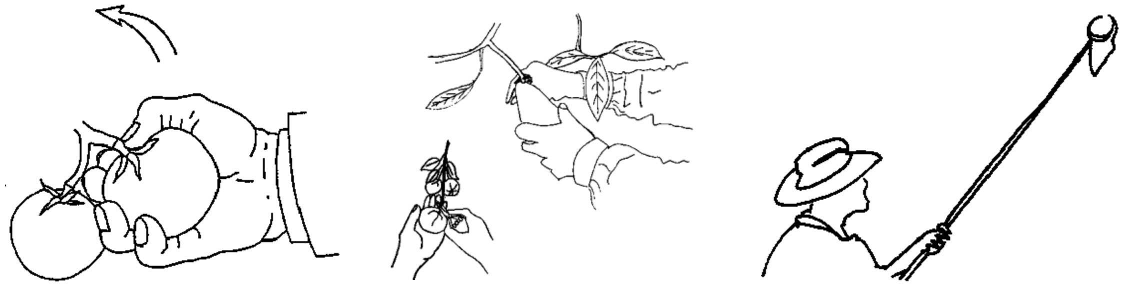
Appendix 4: Harvesting and post-harvesting of plants

1- Harvesting Tools and Containers:

Harvesting is an important operation in horticultural crop production, unscientific harvesting results in damage of crop which can be caused by compression, impact or vibration (Sudheer et al., 2007, p.p. 39).

Depending on the type of fruit or vegetable, several devices are employed to harvest produce. Commonly used tools for harvesting are secateurs or knives, and hand held or pole mounted picking shears *(manual harvesting)* (FAO, 1989), or harvesting crop by

shaking tree or cane by mechanical vibration and catching fruit underneath in a large blanket or net *(Mechanical harvesting)* (Sudheer et al., 2007, p.p. 40).

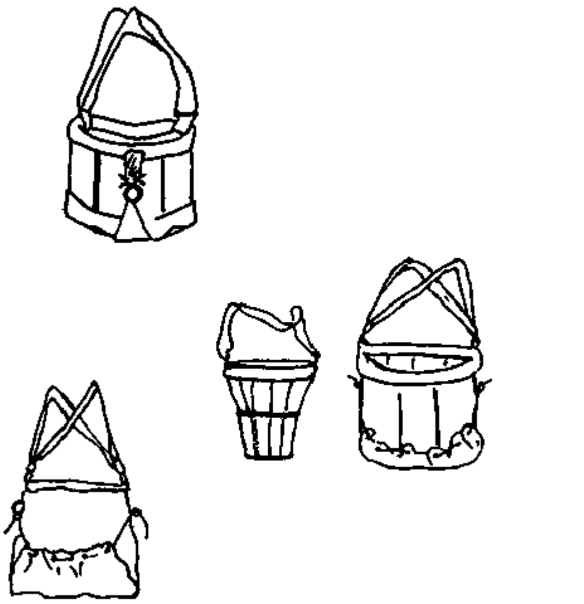


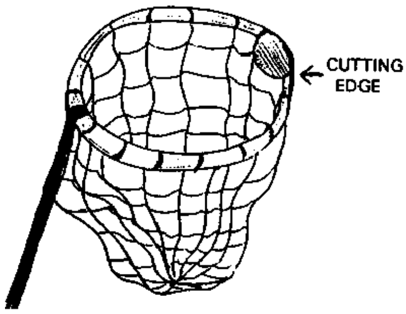
(A) manual harvesting, gentle picking | **(B)** Clippers or knives harvesting tools | **(C)** picking pole

Figure 17. Harvesting tools

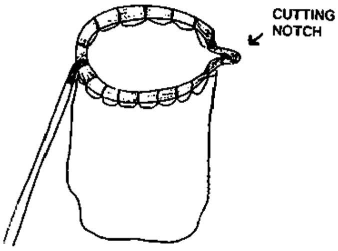
Source: (Kitinoja and Kade, 1995)

Harvesting containers must be easy to handle for workers picking fruits and vegetables in the field. Many crops are harvested into bags. Harvesting bags with shoulder or waist slings can be used for fruits. Sacks are commonly used for crops such as potatoes, onions, cassava, and pumpkins. Other types of field harvest containers include baskets, buckets, carts, and plastic crates (Kitinoja and Kade, 1995).





(B) collection bag



(A) Picking baskets, bags and buckets

(C) collection sack

Figure 18. Picking baskets, bags and buckets
Source: (Kitinoja and Kade, 1995)

2- Packaging process, containers and internal transport:

Harvested crops have to reach a ***"packinghouse"*,** where operations like cleaning, grading, post-grading treatments, and packing for transport and marketing, are done*)* (Sudheer et al., 2007, p.p. 7). The location of packing house should be access to the field and market point, and ease of access to labor (FAO, 2012).

There are two systems of packaging, manual packing system, and automated packing system:

A circular rotating table can be used to pack a variety of crops. The produce is simply put onto the table, where packers select the produce and fill cartons at their stations.

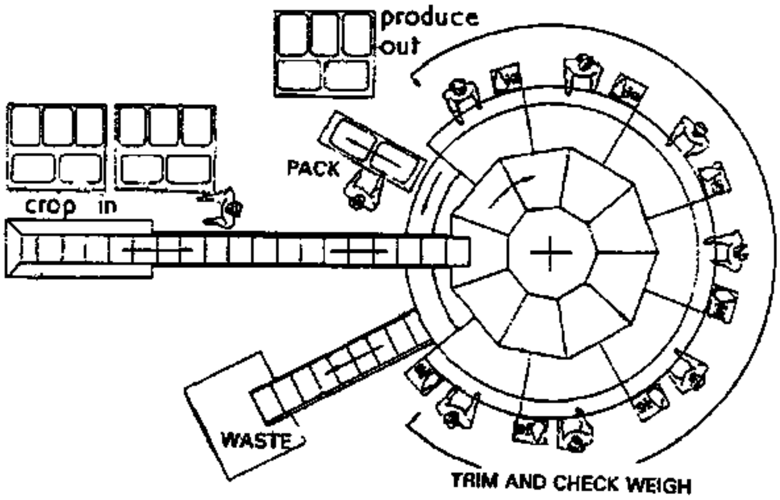
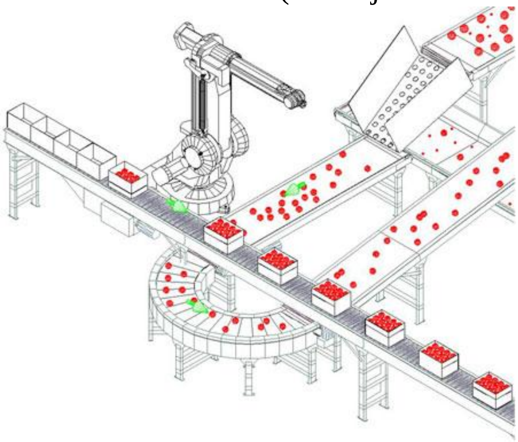


Figure 19. Manual Packing systems
Source: (Kitinoja and Kade, 1995)

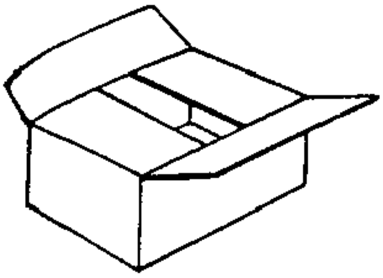


(A) Robotic Packing System, **Source:** http://www.cisco-eagle.com/**,** retrieved May 11, 2012.

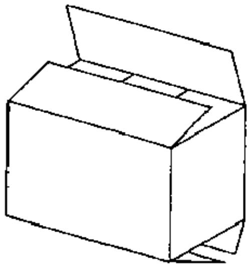
(B) Tomatoes automated packing system **Source:** http://4.bp.blogspot.com/, retrieved May 11, 2012.

Figure 20. Automated packing machine

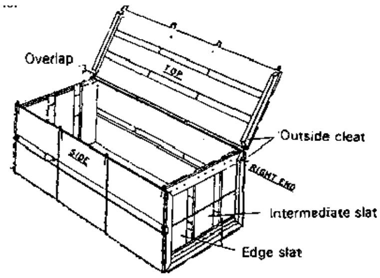
There are many types of packing containers; Packages can be classified as illustrated in the following *Figure.*



(A) fiberboard container

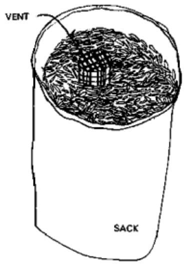


(B) fiberboard container

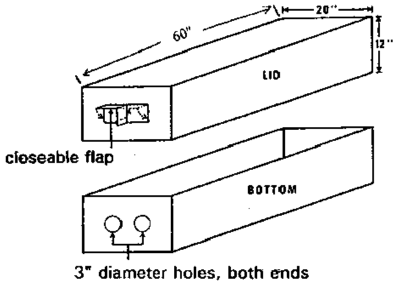


(C) wooden crates

(D) typical plastic crate



(E) large bags with a vent



(F) container for cut flowers

Figure 21. Packaging containers

Source: (Kitinoja and Kade, 1995)

Glossary

Urban agriculture It is an industry that produces processes, and markets food, fuel, and other outputs, largely in response to the daily demand of consumers within a town, city, or metropolis, on many types of privately and publicly held land and water bodies found throughout intra-urban and peri-urban areas.

Rooftop farming It is the practice of cultivating food on the rooftop of buildings. Rooftop farming is usually done using hydroponics, aeroponics, or container gardens.

Vertical farming It is a proposed agriculture technique involving large scale agriculture in urban high-rises or farm scrapers within a city farming fruit, vegetables, and grains inside of a building where different floors have different purposes, using recycled resources, and greenhouse methods such as hydroponics, and aeroponic system, artificial sunlight, and other available technologies.

Hydroponic system Hydroponics comes from a Latin word: hydro meaning water and ponos meaning labor which literally means "working water". Hydroponics is a method of growing plants using mineral nutrient solutions without soil.

تخطيط وتصميم المزارع العمودية : آفاق الزراعة الحضرية في فلسطين

اعداد

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المشرف

د. نبيل أبو دية

الملخص

تم التركيز في اطروحة البحث عن امكانية وجود مباني زراعية رأسية داخل مدننا الحضرية و مدى جدواها الاقتصادية و البيئية.

تهدف الرسالة الى معالجة ما يلي: هل المزارع العمودية هي الحل الانسب لنقص الغذاء العالمي، و نقص المياه، و عدم توفر الاراضي الزراعية ؟ ما هي المبادئ التوجيهية العامة لتصميم نموذج اولي من المزارع الرأسية ، و ما هي المعايير التي تحكم اختيار المكان المناسب؟

في استكشاف هذا الموضوع ، الهدف الرئيسي من الاطروحة هو تخطيط ووضع تصور لنموذج مبنى المزرعة العمودية التي يمكن اقامتها داخل مدننا في المناطق الحضرية.

تم التوصل في الاستنتاجات ان البناء المقترح للمزرعة العمودية و التي تتكون من 10 طوابق, و يبلغ اجمالي مساحتها 12000 م2 ، و تحتل 3 دونم افقيا، قادرة على اطعام 10000 شخص و اكثر، و بتكلفة 15 مليون دينار ، كما انها حققت عدة اهداف: مجموع انتاج المحصول في المزارع الرأسية يساوي عدة مرات من انتاج المحصول باستخدام اساليب الزراعة التقليدية.

بالاضافة الى ذلك فان نفس الكمية من المحاصيل التي تنتجها المزرعة العمودية تحتاج 150 دونم من الاراضي الصالحة للزراعة باستخدام اساليب الزراعة التقليدية.

اخيرا، تم اقتراح توصيات عملية لجعل مفهوم الزراعة الرأسية يتحول الى ارض الواقع من خلال تعاون الحكومات المحلية و الباحثين و المعماريين و الاقتصاديين و المهندسين الزراعيين.